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IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

STANDARDS

IEEE Power and Energy Society

Developed by the
Energy Storage and Stationary Battery Committee

IEEE Std 485™-2020
(Revision of IEEE Std 485-2010)

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IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

Sponsor

Energy Storage and Stationary Battery Committee
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IEEE Power and Energy Society

Approved 6 May 2020

IEEE SA Standards Board

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Abstract: Methods for defining the dc load and for sizing a lead-acid battery to supply that load for stationary battery applications in float service are described in this recommended practice. Some factors relating to cell selection are provided for consideration. Installation, maintenance, qualification, testing procedures, and consideration of battery types other than lead-acid are beyond the scope of this recommended practice. Design of the dc system and sizing of the battery charger(s) are also beyond the scope of this recommended practice.

Keywords: battery duty cycle, cell selection, dc load, full-float operation, IEEE 485™, lead-acid batteries, rated capacity, sizing, stationary applications, valve-regulated lead-acid (VRLA) cell, vented battery, vented lead-acid (VLA)

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Introduction

This introduction is not part of IEEE Std 485-2020, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.

The storage battery is of primary importance for the satisfactory operation of stationary applications including but not limited to generating stations, substations, telecommunications, and other stationary applications. This recommended practice is based on commonly accepted methods used to define the load and determine adequate battery capacity. The method described is applicable to all installations and battery sizes.

The installations considered herein are designed for operation with a battery charger serving to maintain the battery in a charged condition as well as to supply the normal dc load. This recommended practice does not apply to "cycling" applications. (See IEEE Std 1660™ [B7].[1])

This recommended practice was prepared by the Vented Lead Acid Sizing Working Group of the Energy Storage and Stationary Battery Committee. It may be used separately, but when combined with IEEE Std 450™[2] and IEEE Std 484™ (for vented lead acid batteries) or IEEE Std 1187™ and IEEE Std 1188™ (for valve-regulated lead-acid [VRLA] batteries), it provides the user with a general guide to designing, placing in service, and maintaining the applicable lead-acid battery installation.

[1]The numbers in brackets correspond to those of the bibliography in Annex H.
[2]Information on references can be found in Clause 2.

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IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

1. Scope

Methods are described for defining the dc load and for sizing a lead-acid battery to supply that load for stationary battery applications in float service. Some factors relating to cell selection are provided for consideration. Installation, maintenance, qualification, testing procedures, and consideration of battery types other than lead acid are beyond the scope of this recommended practice. The design of the dc system and sizing of the battery charger(s) are also beyond the scope of this recommended practice.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they shall be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 450™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.[3,4]

IEEE Std 484™, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications.

IEEE Std 1184™-2006, IEEE Guide for Batteries for Uninterruptible Power Supply Systems.

IEEE Std 1187™, IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications.

IEEE Std 1188™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.

IEEE Std 1881™, IEEE Standard Glossary of Stationary Battery Terminology.

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3. Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online[5], or IEEE Std 1881™, IEEE Standard Glossary of Stationary Battery Terminology, should be consulted for terms not defined in this clause.

cell size: The rated capacity of a cell or the number of positive plates in a cell.

continuous load: Loads that are energized throughout the duty cycle.

coup de fouet: Initial voltage drop and recovery experienced when discharging a lead-acid battery.

duty cycle: The sequence of loads a battery is expected to supply for specified time periods.

equalizing charge: A charge, at a level higher than the normal float voltage, applied for a limited period of time, to correct inequalities of voltage, specific gravity, or state of charge that may have developed between the cells during service.

float service: Operation of a dc system in which the battery spends the majority of the time on float charge with infrequent discharge. *Syn:* **standby service**.

NOTE—The primary source of power is normally the battery charger or rectifier.[6]

momentary load: loads that can occur one or more times during the duty cycle, but are of short duration, not to exceed one minute during any occurrence.

non-continuous load: loads energized only during a portion of the duty cycle.

period: An interval of time in the battery duty cycle during which the current (or power) is assumed to be constant for purposes of cell sizing calculations.

rated capacity: The capacity assigned to a cell by its manufacturer for a given discharge rate, at a specified electrolyte temperature, to a given end-of-discharge voltage.

valve-regulated lead-acid (VRLA) cell: A lead-acid cell that is sealed with the exception of a valve that opens to the atmosphere when the internal pressure in the cell exceeds atmospheric pressure by a preselected amount. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.

vented cell: A cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. *Syn:* **flooded cell**.

NOTE—**vented cell** is the preferred term that should be used in place of **wet cell** or **flooded cell**.

[5]IEEE Standards Dictionary Online subscription is available at: http://ieeexplore.ieee.org/xpls/dictionary.jsp. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

[6]Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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4. Defining loads

4.1 General considerations

The duty cycle imposed on the battery by any of the conditions described herein depends on the dc system design and the requirements of the installation. The battery supplies the dc power requirements when one or more of the following conditions occur:

a) Load on the dc system exceeds the maximum output of the battery charger

b) Output of the battery charger is interrupted

c) AC power to the battery charger is lost [may result in a greater dc power demand than item b)]

The most severe of these conditions, in terms of battery load and duration, should be used to determine the battery size for the installation.

4.2 Load classification

The individual dc loads supplied by the battery during the duty cycle are classified as continuous or noncontinuous. Noncontinuous loads lasting 1 min or less are designated “momentary loads” and should be given special consideration (see 4.2.3).

4.2.1 Continuous loads

Continuous loads are energized throughout the duty cycle. These loads are those normally carried by the battery charger and those initiated at the inception of the duty cycle. Typical continuous loads are as follows:

a) Lighting

b) Continuously operating motors

c) Converters (e.g., inverters)

d) Indicating lights

e) Continuously energized coils

f) Annunciator loads

g) Communication systems

h) Power Supplies (e.g., Relay protection, security systems, battery monitors)

4.2.2 Noncontinuous loads

Noncontinuous loads are energized only during a portion of the duty cycle. These loads come on at any time within the duty cycle and remain on for a set length of time, or be removed automatically or by operator action, or continue to the end of the duty cycle. Typical noncontinuous loads may include:

a) Emergency pump motors

b) Critical ventilation system motors

c) Fire protection systems actuations

d) Motor-driven valve operations (stroke time > 1 min)

e) Other ac loads on the output of inverters

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4.2.3 Momentary loads

Momentary loads can occur one or more times during the duty cycle but are of short duration, not exceeding 1 min at any occurrence. Although momentary loads may exist for only a fraction of a second, it is common practice to treat each load as if it lasts for a full minute because the battery voltage drop after several seconds often determines the battery's 1-min rating. When several momentary loads occur within the same 1-min period and a discrete sequence cannot be established, the load for the 1-min period should be assumed to be the sum of all momentary loads occurring within that minute. If a discrete sequence can be established, the load for the period is the maximum load at any instant. Sizing for a load lasting only a fraction of a second, based on the battery's 1-min performance rating, results in a conservatively sized battery. Consult the battery manufacturer for ratings of discharge durations less than 1 min. Typical momentary loads may include:

a) Switchgear operations
b) Motor-driven valve operations (stroke time < 1 min)
c) Motorized switch operations
d) Field flashing of generators
e) Motor starting currents
f) Inrush currents

4.2.4 Other considerations

The loads applied to the battery are normally categorized as constant power, constant resistance, or constant current. However, for sizing purposes, the loads are treated as constant power or constant current. The designer should review each system to be sure all possible loads and their variations are included. If the loads are solely constant power loads, sizing as described in Annex D is appropriate and simplifies the sizing process.

4.2.5 Duty cycle diagram

A duty cycle diagram showing the total load at any time during the cycle is an aid in the analysis of the duty cycle. To prepare such a diagram, all loads (expressed in either current or power) expected during the cycle are tabulated along with their anticipated inception and shutdown times. The total time span of the duty cycle is determined by the requirements of the installation.

4.2.6 Defined loads

Loads whose inception and shutdown times are known are plotted on the diagram as they would occur. If the inception time is known, but the shutdown time is indefinite, it should be assumed that the load continues through the remainder of the duty cycle. Similarly, if the shutdown time is known, but the inception is not, it should be assumed that the load begins when the duty profile begins.

4.2.7 Random loads

Loads that occur at random should be shown at the most critical time of the duty cycle in order to simulate the worst-case load on the battery. These are noncontinuous or momentary loads as described in 4.2.2 and 4.2.3. To determine the most critical time, it is necessary to size the battery without the random load(s) and to identify the section of the duty cycle that controls battery size. Then the random load(s) should be superimposed on the end of that controlling section as shown in Figure 1 (see 6.4.4).

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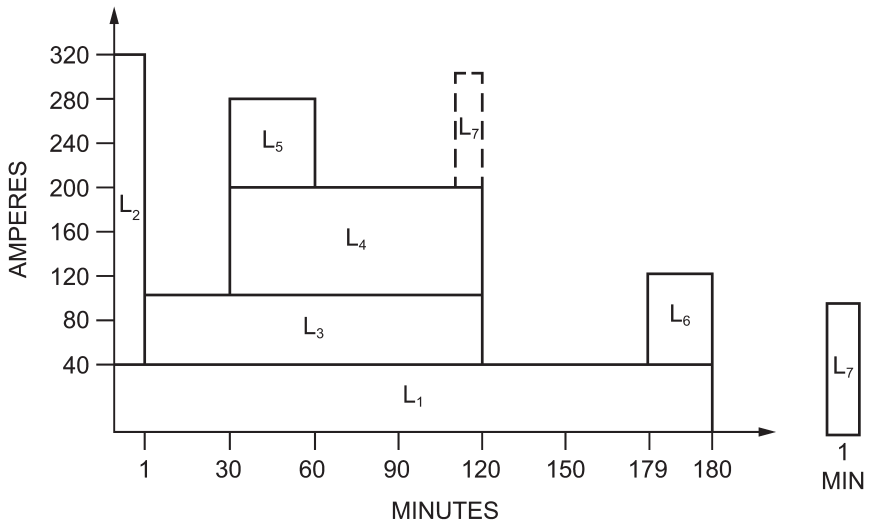

NOTE—This example is worked out in detail in Annex A. There it is found that the first 120 min is the controlling portion of the duty cycle. Therefore, the random load is located on the duty cycle so that the random load ends at the end of the 120th min. This is indicated by the dashed lines. See Annex F for an additional discussion on treatment of random loads.

Figure 1—Diagram of a duty cycle

4.2.8 Duty cycle example

Figure 1 is a diagram of a duty cycle made up of the following hypothetical loads expressed in amperes:

- L_1 40 A for 3 h, continuous load
- L_2 280 A for the 1st min, momentary load, actually 5 s starting current to load L_3
- L_3 60 A from the 1st min through the 120th min, noncontinuous load
- L_4 100 A from the 30th min through the 120th min, noncontinuous load
- L_5 80 A from the 30th min through the 60th min, noncontinuous load
- L_6 80 A for the last minute, momentary load, actually a known sequence of: 40 A for the first 5 s, 80 A for the next 10 s, 30 A for the next 20 s
- L_7 100 A for 1 min, random load (Actually this consists of four 25 A momentary loads that can occur at any time within the duty cycle. Therefore, the assumption is that they all occur simultaneously.)

When the duty cycle includes constant power and constant current loads, it is usually more convenient to convert the constant power load values to constant current values for sizing calculations (see Annex D).

5. Cell selection

This clause summarizes some factors that should be considered in selecting a cell design for a particular application. Various cell designs have different charge, discharge, and aging characteristics. Refer to IEEE Std 1184-2006, Annex C of this document, and vendor literature for discussions of cell characteristics.

The following factors should be considered in the selection of the cell (or multi-cell unit):

a) Physical characteristics, such as dimensions and weight of the cells, container material, intercell connectors, and terminals

b) Planned life of the installation and expected service life of the cell

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c) Frequency and depth of discharge

d) Type of discharge (high-rate, long-duration, mixed loads)

e) Ambient temperature (Note that sustained high ambient temperatures result in reduced battery life. See IEEE Std 484 and IEEE Std 1187.)

f) Charging characteristics

g) Maintenance requirements

h) Cell orientation requirements

i) Ventilation requirements

j) Seismic characteristics

k) Spill management

6. Determining battery size

6.1 General

Several basic factors govern the size (number of cells and rated capacity) of the battery, including the maximum system voltage, the minimum system voltage, correction factors, and the duty cycle. Because a battery is usually composed of a number of identical cells connected in series, the voltage of the battery is the voltage of a cell multiplied by the number of cells in series. The ampere-hour capacity of a battery is the same as the ampere-hour capacity of a single cell, which depends upon the dimensions and number of plates.

If cells of sufficiently large capacity are not available, then two or more strings (equal numbers of series-connected cells) should be connected in parallel to obtain the necessary capacity. The capacity of such a battery is the sum of the capacities of the strings. Consult the manufacturer for any limitation on paralleling.

Examples of conditions that can change the available capacity of the battery are as follows:

— The available capacity of the battery decreases as its temperature decreases.

— The available capacity decreases as the discharge rate increases.

— The minimum specified cell voltage at any time during the battery discharge cycle limits the available capacity of the battery.

6.2 Number of cells

6.2.1 General

The maximum and minimum allowable system voltage determines the number of cells in the battery. It has been common practice to use 12, 24, 60, 120, or 240 cells for nominal system voltages of 24 V, 48 V, 125 V, 250 V, or 480 V, respectively. In some cases, it is desirable to vary from this practice to match the battery to system voltage limitations more closely. It should be noted that the use of the widest possible voltage window, within the confines of individual load requirements, results in the most economical battery. Furthermore, the use of the largest number of cells allows the lowest minimum cell voltage and, therefore, the smallest size cell for the duty cycle. The application of the following principles is illustrated in A.2 of Annex A.

Furthermore, the use of the largest number of cells allows the lowest minimum cell voltage and therefore, the smallest size cell for the duty cycle.

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6.2.2 Calculating number of cells and minimum cell voltage

When the battery voltage is not allowed to exceed a given maximum system voltage, the number of cells is limited by the cell voltage required for satisfactory charging or equalizing. The system (load equipment) operating voltage range determines the number of cells that can be used and takes into consideration the charging or equalizing voltage, as in the following equation:

$$\frac{\text{maximum system voltage}}{\text{cell voltage required for equalizing}} = \text{number of cells}$$

Example: Assume 2.33 V/cell is required for equalize charging and that the maximum allowable system voltage is 140 V or 135 V. Then,

$$\frac{140\ \text{V}}{2.33} = 60.09\ \text{cells}\ \ (\text{use 60 cells})$$

$$\frac{135\ \text{V}}{2.33} = 57.94\ \text{cells}\ \ (\text{use 58 cells})$$

If the number of cells is rounded up, the charging voltage should then be recalculated and verified for adequacy of operation.

The minimum battery voltage equals the minimum system voltage plus the cable voltage drop. All voltage drops should be considered. For example, unusually long cable connections or connectors with greater resistance values than used to rate the battery may require an adjustment to the minimum battery voltage. The minimum battery voltage is then used to calculate the allowable minimum cell voltage.

$$\frac{\text{minimum battery voltage}}{\text{number of cells}} = \text{minimum cell voltage}$$

In an application with a wide voltage window, particularly when long discharge times are required, the minimum cell voltage recommended by the manufacturer for a given discharge time may be a factor. If so, reduce the number of cells in the preceding calculation so that the minimum cell voltage per cell does not fall below the recommended value.

Example: Assume that the minimum battery voltage for the example is 105 V. Then

$$\frac{105\ \text{V}}{60\ \text{cells}} = 1.75\ \text{V/cell}$$

$$\frac{105\ \text{V}}{58\ \text{cells}} = 1.81\ \text{V/cell}$$

This minimum cell voltage is then used in the sizing calculation.

6.3 Additional considerations

6.3.1 General

Before proceeding to calculate the cell capacity required for a particular installation, the designer should consider factors that influence cell size.

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6.3.2 Temperature correction factor

The available capacity of a cell is affected by its operating temperature. If the lowest expected electrolyte temperature is below the rated battery temperature, select a cell large enough to have the required capacity available at the lowest expected temperature. If the lowest expected electrolyte temperature is above the rated battery temperature, it is a conservative practice to select a cell size to match the required capacity at the standard temperature and to recognize the resulting increase in available capacity as part of the overall design margin. Table 1 lists cell size correction factors for various temperatures for lead-acid cells with nominal 1.215 specific gravity. For unlisted temperatures within the range of Table 1, interpolate between adjacent values and round off to two decimal places. Consult the manufacturer for factors for the specific battery being evaluated.

NOTE—The standard US temperature for rating cell capacity is 25 °C (77 °F). Some European manufactures use 20 °C (68 °F).

Table 1—Cell size correction factors for temperature for vented and VRLA cells

Electrolyte temperature (°C)	Electrolyte temperature (°F)	Temperature correction factor	Electrolyte temperature (°C)	Electrolyte temperature (°F)	Temperature correction factor
4.4	40	1.300	26.1	79	0.987
7.2	45	1.250	26.7	80	0.980
10.0	50	1.190	27.2	81	0.976
12.8	55	1.150	27.8	82	0.972
15.6	60	1.110	28.3	83	0.968
18.3	65	1.080	28.9	84	0.964
18.9	66	1.072	29.4	85	0.960
19.4	67	1.064	30.0	86	0.956
20.0	68	1.056	30.6	87	0.952
20.6	69	1.048	31.1	88	0.948
21.1	70	1.040	31.6	89	0.944
21.7	71	1.034	32.2	90	0.940
22.2	72	1.029	35.0	95	0.930
22.8	73	1.023	37.8	100	0.910
23.4	74	1.017	40.6	105	0.890
23.9	75	1.011	43.3	110	0.880
24.5	76	1.006	46.1	115	0.870
25.0	77	1.000	48.9	120	0.860
25.6	78	0.994			

NOTE—This table is based on lead-acid nominal 1.215 specific gravity cells rated at 25 °C (77 °F). For cells with other specific gravities or rated temperatures, refer to the manufacturer.

6.3.3 Design margin

It is prudent to provide a capacity margin to allow for unforeseen additions to the dc system and less-than-optimum operating conditions of the battery due to improper maintenance, recent discharge, ambient temperatures lower than anticipated, or a combination of these factors. A method of providing this design margin is to add 10% to 15% to the cell size determined by calculations. If the various loads are expected to grow at different rates, it is more accurate to apply the expected growth rate to each load for a given time and to develop a duty cycle from the results.

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The cell size calculated for a specific application seldom matches a commercially available cell exactly, and it is normal procedure to select the next higher capacity cell. The additional capacity obtained can be considered part of the design margin.

Note that margins are also discussed in clause 6.3.1.5 and clause 6.3.3 of IEEE Std 323™ [B2]. However, those margins are applied during qualification and are not related to the design margins described in this clause.

6.3.4 Aging factor

As a rule, for long-duration discharges of a vented lead-acid battery, the capacity slowly declines throughout most of the battery's life, but begins to decrease rapidly in the latter stages, with the "knee" of the life versus capacity curve occurring when the remaining capacity is reduced to approximately 80% of rated capacity. This characteristic is well documented for discharges at the 1 h rate or longer.

Because of that, IEEE Std 450 and IEEE Std 1188 recommend that a battery be replaced when its actual capacity drops to 80% of its rated capacity. Therefore, to maintain the battery's capability of meeting its design loads throughout its service life, the battery's rated capacity should be at least 125% (1.25 aging factor) of the load expected at the end of its service life.

For high-rate, short-duration discharges of vented lead-acid batteries and all discharges of VRLA batteries, there are too many variables to state definitively where the "knee" occurs. Therefore, it is reasonable to expect its short-duration performance to drop significantly below 80% of its rating before it reaches the "knee" at that rate so a larger aging factor may be appropriate. Consult with the battery manufacturer for additional information and recommendations.

Exceptions to this rule exist. For example, some manufacturers recommend that vented batteries with Planté, and modified Planté be replaced when their measured capacity drops below 100% of their rated capacity (1.00 aging factor). These designs maintain a fairly constant capacity throughout their life.

6.3.5 Initial capacity

Batteries may have less than rated capacity when delivered. Unless 100% capacity upon delivery is specified, batteries may be delivered with capacities as low as 90% of rating. This should rise to rated capacity in normal service after several charge–discharge cycles or after several years of float operation.

If the designer has provided a 1.25 aging factor, there is no need for the battery to have full rated capacity upon delivery because the capacity normally available from a new battery is above the duty cycle requirement. When a 1.00 aging factor is used, the designer should verify that the initial capacity upon delivery is at least 100% or that there is sufficient margin in the sizing calculation to accommodate a lower initial capacity.

Example: If the cells have 90% initial capacity and the margin is greater than 11%, then no additional compensation for initial capacity is required.

6.4 Cell size

This subclause describes and explains a proven method of calculating the cell capacity necessary for satisfactory performance on a given duty cycle. The application of this method to a specific duty cycle, using an optional preprinted worksheet to simplify the calculations, is demonstrated in A.3 of Annex A. Instructions for the proper use of the worksheet are given in 6.5.

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6.4.1 Initial calculation

Equation (1) (see 6.4.2) requires the use of a capacity rating factor C_t (see 6.4.3) that is based on the discharge characteristics of a particular plate type and size. Thus, the initial calculation is based on a trial selection of positive plate type and capacity. Depending on the results of this initial calculation, it may be desirable to repeat the calculation for other types or sizes of plates to obtain the optimum cell type and size for the particular application. In addition, it may be desirable to repeat the calculation to take into account any differences in performance per plate within a given series of cells. Use the capacity from the first calculation as a guide for selecting additional types to size.

6.4.2 Sizing methodology

The cell selected for a specific duty cycle shall have enough capacity to carry the combined loads during the duty cycle. To determine the required cell size, it is necessary to calculate, from an analysis of each section of the duty cycle (see Figure 2), the maximum capacity required by the combined load demands (current versus time) of the various sections. The first section analyzed is the first period of the duty cycle. Using the capacity rating factor (see 6.4.3) for the given cell type, a cell size is calculated that is capable of supplying the required current for the duration of the first period. For the second section, the capacity is calculated assuming that the current A_1, required for the first period, continued through the second period; this capacity is then adjusted for the change in current ($A_2 - A_1$) during the second period. In the same manner, the capacity is calculated for each subsequent section of the duty cycle. This iterative process is continued until all sections of the duty cycle have been considered. The calculation of the capacity F_S required by each section S, where S can be any integer from 1 to N, is expressed mathematically in Equation (1). F_S is expressed as watt-hours, ampere-hours, or number of positive plates, depending upon which C_t is used (see 6.4.3).

$$F_s = \sum_{P=1}^{P=S} \frac{A_P - A_{(P-1)}}{C_t} \tag{1}$$

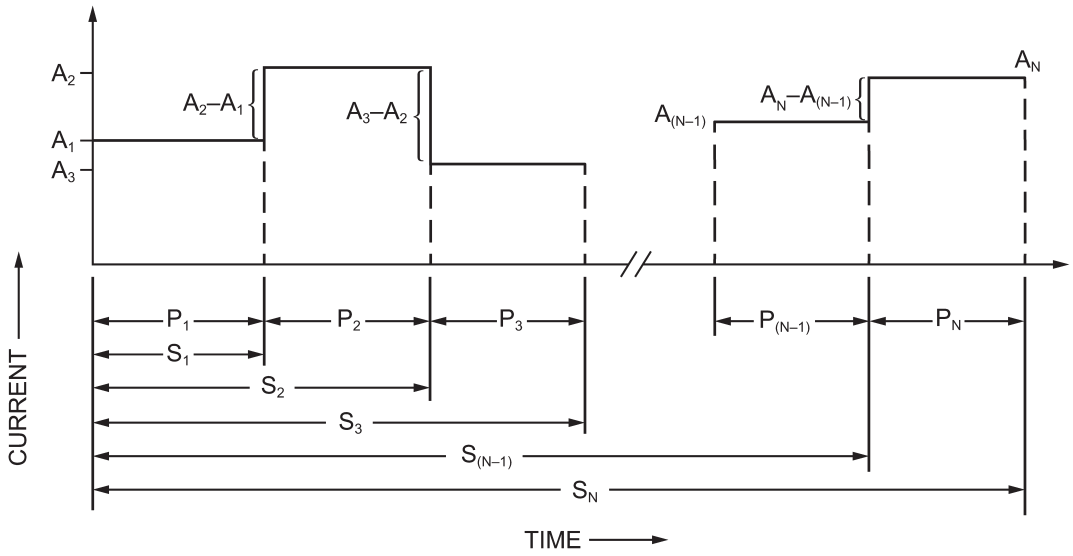

Figure 2—Generalized duty cycle

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The maximum capacity (max F_S) calculated determines the uncorrected cell size that can be expressed by the general Equation (2):

$$F = \max_{S=1}^{S=N} F_S = \max_{S=1}^{S=N} \sum_{P=1}^{P=S} \frac{A_P - A_{(P-1)}}{C_t} \tag{2}$$

where

- F is the cell size (uncorrected for temperature, aging, and design margin)
- S is the section of the duty cycle being analyzed. [Section S contains the first S periods of the duty cycle (e.g., section S_5 contains periods S_1 through S_5). See Figure 2 for a graphical representation of "section."]
- N is the number of periods in the duty cycle
- P is the period being analyzed
- A_P are the amperes required for period P
- t is the time in minutes from the beginning of period P through the end of Section S
- C_t is the capacity rating factor (see 6.4.3) for a given cell type, at the t minute discharge rate, at 25 °C (77 °F), to a definite minimum cell voltage
- F_S is the capacity required by each section

If the current for period $P+1$ is greater than the current for period P, then section $S = P+1$ requires a larger cell than section $S = P$. Consequently, the calculations for section $S = P$ can be omitted.

6.4.3 Capacity rating factor

There are two terms for expressing the capacity rating factor C_t of a given cell type in cell sizing calculations. R_t is the number of amperes that each positive plate can supply for t min at 25 °C (77 °F) to a definite minimum cell voltage. Therefore, $C_t = R_t$ and

$$F = \max_{S=1}^{S=N} F_S = \max_{S=1}^{S=N} \sum_{P=1}^{P=S} \frac{A_P - A_{P-1}}{R_t} \tag{3}$$

K_t is the ratio of rated ampere-hour capacity [at a standard time rate at 25 °C (77 °F) and to a standard minimum cell voltage] of a cell to the amperes that can be supplied by that cell for *t* minutes at 25 °C (77 °F) and to a given minimum cell voltage. Therefore, $C_t = 1/K_t$ and Equation (3) can be rewritten as follows:

$$F = \max_{S=1}^{S=N} F_S = \max_{S=1}^{S=N} \sum_{P=1}^{P=S} \left[A_P - A_{(P-1)}\right] K_t \tag{4}$$

R_t is not equal to $1/K_t$ because of the different units applied to each factor. However, R_t is proportional to $1/K_t$. The values are obtained from battery manufacturers for each positive plate design and various minimum cell voltages. A similar factor, P_t, expressed as watts per positive plate, can be used for calculations involving batteries with only constant-power loads.

Batteries experience a voltage dip during the early stage of discharge, following which the voltage shows some recovery. The designer should verify that this effect (known as the coup de fouet) has been taken into account in the manufacturer's published capacity rating factor. For additional discussion of coup de fouet, see E.2.3.

A battery discharge curve is often used to obtain R_t values and can also provide other useful information about specific battery characteristics. An example of a battery discharge characteristic curve is provided in Annex E along with information on how it is developed and other useful information that can be found on these curves.

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6.4.4 Sizing to include random loads

When equipment loads that occur at random are included as part of the duty cycle, it is necessary to calculate the cell size required for the duty cycle without the random load(s) and then add to this the cell size required for the random load(s) only. See Annex F for additional discussions regarding random loads.

6.4.5 Number of plates per cell

When used with the factor R_t (amperes per positive plate), the general equation expresses the cell size as the number of positive plates. In the manufacturer's literature, the cell size may be listed as the total number of positive and negative plates. The conversion from number of positive plates to the total number of plates is as follows: total number of plates = 1 + (2 × number of positive plates).

6.5 Cell sizing worksheet

A worksheet, given in Figure 3, has been designed to simplify the manual application of the procedure described in 6.4[7]. Examples of its use are found in Annex A. Instructions for the proper use of the worksheet are as follows:

a) Fill in necessary information in the heading of the chart. The temperature and voltage recorded are those used in the calculations. The voltage used is the minimum battery voltage divided by the number of cells in the battery.

b) Fill in the amperes and the minutes in Columns (2) and (4) as indicated by the section heading notations.

c) Calculate and record the changes in amperes as indicated in Column (3). Record whether the changes are positive or negative.

d) Calculate and record the times from the start of each period to the end of the section as indicated in Column (5).

e) Record in Column (6) the capacity factors (R_t or K_t, from the manufacturer's literature) for each discharge time calculated in Column (5).

f) Calculate and record the cell size for each period as indicated in Column (7). Note the separate subcolumns for positive and negative values.

g) Calculate and record in Column (7) the subtotals and totals for each section as indicated.

h) Record the maximum section size [the largest total from Column (7) on Line (8), the random section size on Line (9), and the uncorrected size on Lines (10) and (11)].

i) Select the correction factor from Table 1 or from the manufacturer's published data for the temperature shown in the main heading and record it on Line (12).

j) Enter the design margin on Line (13) and the aging factor on Line (14). Combine Lines (11), (12), (13), and (14) as indicated and record the result on Line (15).

k) When Line (15) is in terms of ampere-hours and does not match the capacity of a commercially available cell, the next larger cell is required. When Line (15) shows a fractional number of positive plates, use the next larger integer. Show the result on Line (16).

l) From the value on Line (16), the equation in 6.4.5, and the manufacturer's literature, determine the commercial designation of the required cell and record it on Line (17).

m) Verify that the factors and discharge rates used are appropriate for the selected size. If not, sizing should be performed again using the factors and discharge rates for the selected cell size.

[7] Annex G contains a full-size worksheet that users of this recommended practice may freely reproduce so that it can be used for their intended purposes.

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Project: Date: Page:

Lowest Expected Electrolyte Temp: °F | Minimum Cell Voltage: | Cell Mfg: | Cell Type: | Sized By:

(1)	(2)	(3)	(4)	(5)	(6)		(7)	
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity at T Min Rate (6A) Amps / Pos (R_T) or (6B) K Factor (K_T)		Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs: Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.								
1	A1=	A1–0=	M1=	T=M1=				***
					Sec 1	Total		***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.								
1	A1=	A1–0=	M1=	T=M1+M2=				
2	A2=	A2–A1=	M2=	T=M2=				
					Sec 2	Sub Tot / Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.								
1	A1=	A1–0=	M1=	T=M1+M2+M3=				
2	A2=	A2–A1=	M2=	T=M2+M3=				
3	A3=	A3–A2=	M3=	T=M3=				
					Sec 3	Sub Tot / Total		***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.								
1	A1=	A1–0=	M1=	T=M1+. . . M4=				
2	A2=	A2–A1=	M2=	T=M2+M3+M4=				
3	A3=	A3–A2=	M3=	T=M3+M4=				
4	A4=	A4–A3=	M4=	T=M4=				
					Sec 4	Sub Tot / Total		***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.								
1	A1=	A1–0=	M1=	T=M1+. . . M5=				
2	A2=	A2–A1=	M2=	T=M1+. . . M5=				
3	A3=	A3–A2=	M3=	T=M3+M4+M5=				
4	A4=	A4–A3=	M4=	T=M4+M5=				
5	A5=	A5–A4=	M5=	T=M5=				
					Sec 5	Sub Tot / Total		***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.								
1	A1=	A1–0=	M1=	T=M1+. . . M6=				
2	A2=	A2–A1=	M2=	T=M1+. . . M6=				
3	A3=	A3–A2=	M3=	T=M1+. . . M6=				
4	A4=	A4–A3=	M4=	T=M4+M5+M6=				
5	A5=	A5–A4=	M5=	T=M5+M6=				
6	A6=	A6–A5=	M6=	T=M6=				
					Sec 6	Sub Tot / Total		***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.								
1	A1=	A1–0=	M1=	T=M1+. . . M7=				
2	A2=	A2–A1=	M2=	T=M1+. . . M7=				
3	A3=	A3–A2=	M3=	T=M1+. . . M7=				
4	A4=	A4–A3=	M4=	T=M1+. . . M7=				
5	A5=	A5–A4=	M5=	T=M5+M6+M7=				
6	A6=	A6–A5=	M6=	T=M6+M7=				
7	A7=	A7–A6=	M7=	T=M7=				
					Sec 7	Sub Tot / Total		***
Random Equipment Load Only (if needed)								
R	AR=	AR–0=	MR=	T=MR=				***

Maximum Section Size (8) _____ + Random Section Size (9) _____ = Uncorrected Size – (US) (10) _____.

US (11) _____ × Temp Corr (12) _____ × Design Marg (13) 1. _____ × Aging Factor (14) 1. _____ = (15) _____.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) _____

(B) - Ampere Hours. Therefore cell (17) _____ is required.

Figure 3—Cell sizing worksheet

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7. Cell voltage/time profile calculation

When the battery sizing procedure and methods described above are used for the specified duty cycle and the cell size selected, the average cell voltage will not drop below the specified minimum (e.g., 1.67 V, 1.75 V, or 1.81 V) at any point in the duty cycle. It is therefore not normally necessary to calculate the cell or battery terminal voltage because it remains above the predetermined allowable minimum through the discharge period. If the need for such information should arise, Annex B describes one method of calculating the voltage at various points in the duty cycle utilizing the typical discharge characteristic curves published by the battery manufacturer.

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Annex A

(informative)

Battery and cell sizing examples

A.1 General

The following examples use the same duty cycle discussed in 4.2.8 with a lowest expected electrolyte temperature of 18.3 °C (65 °F). Subclause A.2 provides several examples of calculations selecting the number of cells to be used in the battery and shows how the number of cells affects the required cell capacity. Subclause A.3 shows how the cell sizing worksheet can be used to calculate the required cell size.

A.2 Required number of cells

A.2.1 Example number 1

The following example describes two cases where system design affects the number of cells. For both cases, the voltage window is 105 V to 140 V, and the battery manufacturer recommends a float voltage of 2.25 V/cell and equalizing at 2.33 V/cell.

Case 1

The battery and charger are continuously connected to the loads.

$$\text{Number of cells} = \frac{140\ \text{V}}{2.33\ \text{V/cell}} = 60.09\left(\text{use 60 cells}\right)$$

$$\text{End-of-discharge voltage} = \frac{105\ \text{V}}{60\ \text{cells}} = 1.75\ \text{V/cell}$$

This case is worked out in detail in Figure A.1 and results in a corrected size of 1010.4 Ah at the 8-h rate using 1.75 minimum cell voltage with the K_t rating factor.

Case 2

The battery and charger are isolated from the loads during equalizing.

$$\text{Number of cells} = \frac{140\ \text{V}}{2.25\ \text{V/cell}} = 62.2\left(\text{use 62 cells}\right)$$

$$\text{End-of-discharge voltage} = \frac{105\ \text{V}}{62\ \text{cells}} = 1.69\ \text{V/cell}$$

A cell sizing worksheet is not provided for this example, but calculations show that the corrected cell size is 944 Ah at the 8-h rate. The reduction in the end-of discharge voltage results in about a 7% reduction in corrected cell capacity with only a 3% increase in the number of cells. The equalizing voltage while isolated would be 144.5 V.

Although the example illustrates the effect of using more cells in a string, it is not recommended to size a battery below 1.75 V per cell for discharge times longer than 1 h.

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Project: Example using K_T Capacity Factor Date: 9/17/1977 Page: 1

Lowest Expected Electrolyte Temp: 65 °F Minimum Cell Voltage: 1.75 Cell Mfg: ABC Co Cell Type: XYZ Sized By: J.W.A

(1)	(2)	(3)	(4)	(5)	(6)		(7)	
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity at T Min Rate (6A) Amps / Pos (R_T) or (6B) K Factor (K_T)		Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs: Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.								
1	A1= 320	A1–0= 320	M1= 1	T=M1= 1	0.77		246.4	***
					Sec 1	Total	246.4	***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.								
1	A1=	A1–0=	M1=	T=M1+M2=				
2	A2=	A2–A1=	M2=	T=M2=				
					Sec 2	Sub Tot / Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.								
1	A1= 320	A1–0= 320	M1= 1	T=M1+M2+M3= 60	2.00		640.0	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3= 59	2.00			–440.0
3	A3= 280	A3–A2= 180	M3= 30	T=M3= 1	1.44		259.2	
					Sec 3	Sub Tot	899.2	–440.0
						Total	459.2	***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.								
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M4= 120	2.91		931.2	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3+M4= 119	2.91			–640.2
3	A3= 280	A3–A2= 180	M3= 30	T=M3+M4= 90	2.46		442.8	
4	A4= 200	A4–A3= –80	M4= 60	T=M4= 60	2.00			–160.0
					Sec 4	Sub Tot	1374.0	–800.2
						Total	573.8	***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.								
1	A1=	A1–0=	M1=	T=M1+. . . M5=				
2	A2=	A2–A1=	M2=	T=M1+. . . M5=				
3	A3=	A3–A2=	M3=	T=M3+M4+M5=				
4	A4=	A4–A3=	M4=	T=M4+M5=				
5	A5=	A5–A4=	M5=	T=M5=				
					Sec 5	Sub Tot / Total		***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.								
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M6= 180	3.72		1190.4	
2	A2= 100	A2–A1= –220	M2= 29	T=M1+. . . M6= 179	3.72			–818.4
3	A3= 280	A3–A2= 180	M3= 30	T=M1+. . . M6= 150	3.33		599.4	
4	A4= 200	A4–A3= –80	M4= 60	T=M4+M5+M6= 120	2.91			–232.8
5	A5= 40	A5–A4= –160	M5= 59	T=M5+M6= 60	2.00			–320.0
6	A6= 120	A6–A5= 80	M6= 1	T=M6= 1	0.77		61.6	
					Sec 6	Sub Tot	1851.4	1371.2
						Total	480.2	***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.								
1	A1=	A1–0=	M1=	T=M1+. . . M7=				
2	A2=	A2–A1=	M2=	T=M1+. . . M7=				
3	A3=	A3–A2=	M3=	T=M1+. . . M7=				
4	A4=	A4–A3=	M4=	T=M1+. . . M7=				
5	A5=	A5–A4=	M5=	T=M5+M6+M7=				
6	A6=	A6–A5=	M6=	T=M6+M7=				
7	A7=	A7–A6=	M7=	T=M7=				
					Sec 7	Sub Tot / Total		***
Random Equipment Load Only (if needed)								
R	AR= 100	AR–0= 100	MR= 1	T=MR= 1	0.77		77.0	***

Maximum Section Size (8) 573.8 + Random Section Size (9) 77.0 = Uncorrected Size – (US) (10) 650.8.

US (11) 650.8 × Temp Corr (12) 1.08 × Design Marg (13) 1.15 × Aging Factor (14) 1.25 = (15) 1010.4.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) 1040

(B) - Ampere Hours. Therefore cell (17) XYZ-27 is required.

Figure A.1—Sample worksheet using K_t

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A.2.2 Example number 2

Same conditions as Example 1, Case 1, except that the dc system voltage limits are now 105 V to 135 V.

$$\text{Number of cells} = \frac{135\ \text{V}}{2.33\ \text{V/cell}} = 57.9\left(\text{use 58 cells}\right)$$

$$\text{End-of-discharge voltage} = \frac{105\ \text{V}}{58\ \text{cells}} = 1.81\ \text{V/cell}$$

A cell sizing worksheet is not provided for this example, but calculations show that the corrected cell size is 1186 Ah at the 8-h rate. In comparison to Example 1, the increase in the minimum cell voltage results in a 17% increase in the corrected cell size with only a 3% reduction in the number of cells required.

A.3 Required cell capacity

Table A.1 can be constructed from the duty cycle diagram in Figure A.2. This table is of value in filling out the cell sizing worksheet.

Table A.1—Sample cell sizing data

Period	Loads	Total amperes	Duration (min)
1	$L_1 + L_2$	320	1
2	$L_1 + L_3$	100	29
3	$L_1 + L_3 + L_4 + L_5$	280	30
4	$L_1 + L_3 + L_4$	200	60
5	L_1	40	59
6	$L_1 + L_6$	120	1
R	L_7	100	1

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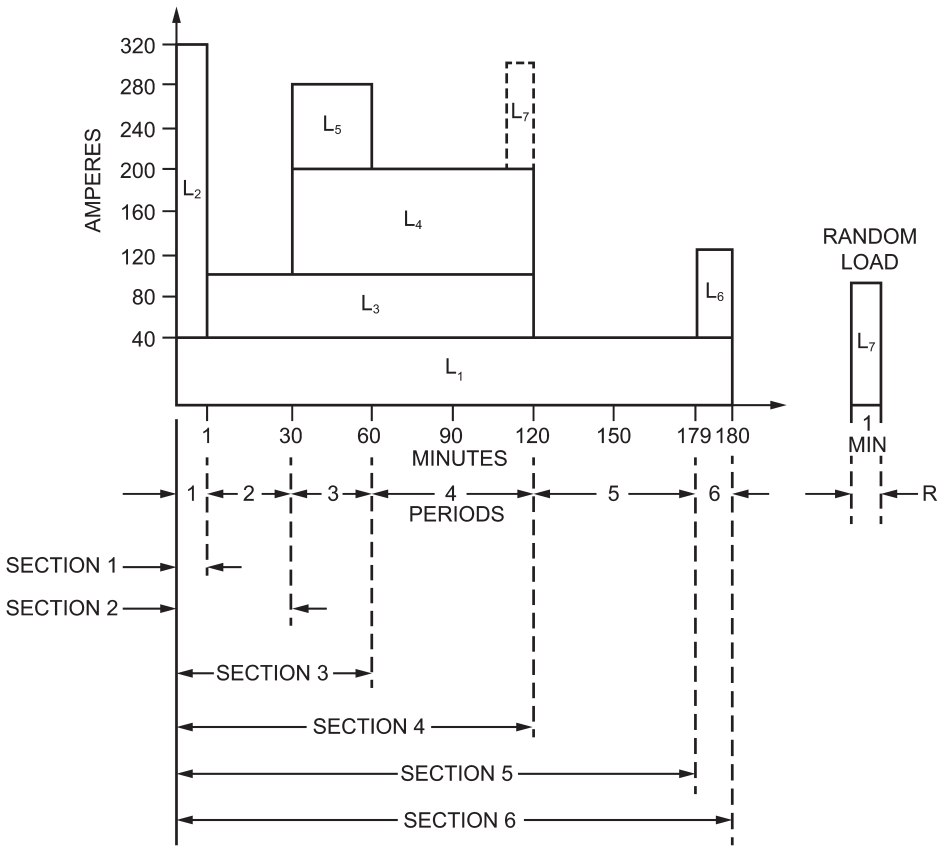

Figure A.2—Duty cycle diagram

Figure A.3 is a hypothetical composite rating curve for the XYZ cell manufactured by the ABC Company. The graph gives values for both types of capacity rating factors for discharges started at 25 °C (77 °F) and terminated when the average cell voltage reaches 1.81 V, 1.75 V, or 1.69 V. Figure A.4 shows the way in which the cell sizing worksheet and the R_t rating factor would be used to size the XYZ cell for the Figure 1 duty cycle.

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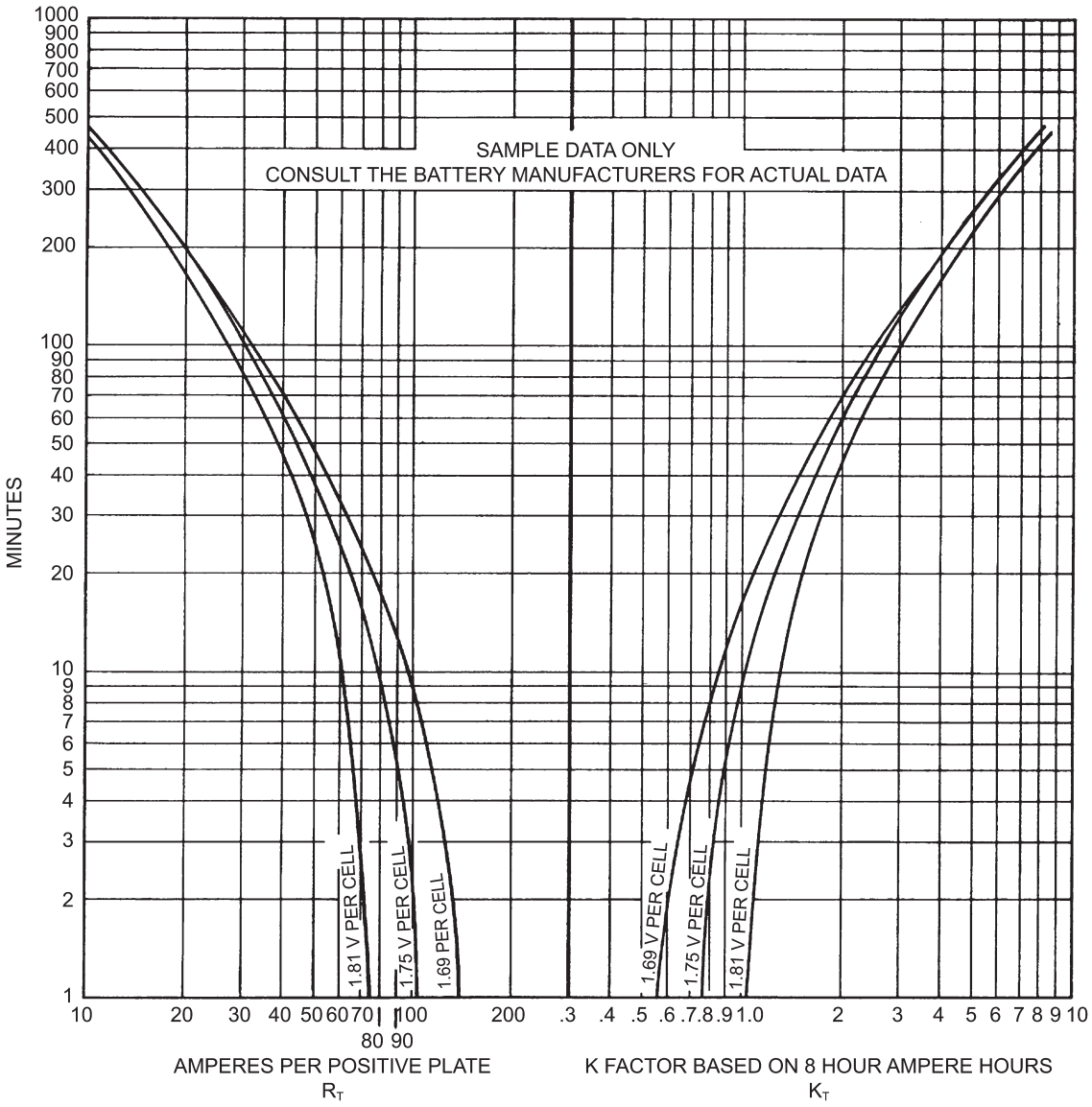

Figure A.3—Hypothetical composite rating curve for XYZ cell manufactured by ABC Company

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Project: Example using R_T Capacity Factor | Date: 9/17/1977 | Page: 1

Lowest Expected Electrolyte Temp: 65 °F | Minimum Cell Voltage: 1.75 | Cell Mfg: ABC Co | Cell Type: XYZ | Sized By: J.W.A

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity at T Min Rate (6A) Amps / Pos (R_T) or (6B) K Factor (K_T)	Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs: Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.							
1	A1= 320	A1–0= 320	M1= 1	T=M1= 1	104	3.08	***
					Sec 1 Total	3.08	***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.							
1	A1=	A1–0=	M1=	T=M1+M2=			
2	A2=	A2–A1=	M2=	T=M2=			
					Sec 2 Sub Tot / Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.							
1	A1= 320	A1–0= 320	M1= 1	T=M1+M2+M3= 60	40.0	8.00	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3= 59	40.0		–5.50
3	A3= 280	A3–A2= 180	M3= 30	T=M3= 30	55.4	3.25	
					Sec 3 Sub Tot	11.25	–5.50
					Total	5.75	***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.							
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M4= 120	27.5	11.64	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3+M4= 119	27.5		–8.00
3	A3= 280	A3–A2= 180	M3= 30	T=M3+M4= 90	32.5	5.54	
4	A4= 200	A4–A3= –80	M4= 60	T=M4= 60	40.0		–2.00
					Sec 4 Sub Tot	17.18	–10.00
					Total	7.18	***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.							
1	A1=	A1–0=	M1=	T=M1+. . . M5=			
2	A2=	A2–A1=	M2=	T=M1+. . . M5=			
3	A3=	A3–A2=	M3=	T=M3+M4+M5=			
4	A4=	A4–A3=	M4=	T=M4+M5=			
5	A5=	A5–A4=	M5=	T=M5=			
					Sec 5 Sub Tot / Total		***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.							
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M6= 180	21.5	14.88	
2	A2= 100	A2–A1= –220	M2= 29	T=M1+. . . M6= 179	21.5		–10.23
3	A3= 280	A3–A2= 180	M3= 30	T=M1+. . . M6= 150	24.0	7.50	
4	A4= 200	A4–A3= –80	M4= 60	T=M4+M5+M6= 120	27.5		–2.91
5	A5= 40	A5–A4= –160	M5= 59	T=M5+M6= 60	40.0		–4.00
6	A6= 120	A6–A5= 80	M6= 1	T=M6= 1	104.0	0.77	
					Sec 6 Sub Tot	23.15	–17.14
					Total	6.01	***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.							
1	A1=	A1–0=	M1=	T=M1+. . . M7=			
2	A2=	A2–A1=	M2=	T=M1+. . . M7=			
3	A3=	A3–A2=	M3=	T=M1+. . . M7=			
4	A4=	A4–A3=	M4=	T=M1+. . . M7=			
5	A5=	A5–A4=	M5=	T=M5+M6+M7=			
6	A6=	A6–A5=	M6=	T=M6+M7=			
7	A7=	A7–A6=	M7=	T=M7=			
					Sec 7 Sub Tot / Total		***
Random Equipment Load Only (if needed)							
R	AR= 100	AR–0= 100	MR= 1	T=MR= 1	104.0	0.96	***

Maximum Section Size (8) 7.18 + Random Section Size (9) 0.96 = Uncorrected Size – (US) (10) 8.14.

US (11) 8.14 × Temp Corr (12) 1.08 × Design Marg (13) 1.15 × Aging Factor (14) 1.25 = (15) 12.64.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) 13

(B) - Ampere Hours. Therefore cell (17) XYZ-27 is required.

Figure A.4—Sample worksheet using R_t capacity factor

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Annex B

(informative)

Calculating cell voltage during discharge

B.1 General

When the battery sizing procedure and methods described in this recommended practice are used for the specified duty cycle and the cell size selected, the average cell voltage does not drop below the specified minimum at any point in the duty cycle. It is not, therefore, normally necessary to calculate the cell or battery terminal voltage because it remains above the predetermined allowable minimum throughout the discharge period. If the need for such information should arise, a method of calculating the voltage at various points in the duty cycle, utilizing the battery manufacturer's typical discharge characteristic curves, is described in B.2 and B.3.

B.2 Method

Two types of typical discharge characteristic curves in common use are "fan" curves and "S" curves, typical examples of which are shown in Figure B.1 and Figure B.2, respectively. Although these two curves have different coordinates and appearance, they show comparable data for two different cell types.

The method of calculation (using either curve) is an iterative process and consists of the following:

a) Keeping a cumulative total of the ampere-hours "removed" from the cell during each discharge segment/period

b) Identifying the discharge current at that time

c) Using this information, along with the battery manufacturer's typical discharge characteristics, to determine the cell terminal voltage at various points in the duty cycle

The voltage/time profile is then a plot of these cell voltages versus time for the entire duty cycle. To determine the voltage just before and just after a step change in the discharge rate, keep the cumulative ampere-hours constant and determine the voltage based on the two different (before and after) discharge rates. The battery terminal voltage at each point is equal to the average cell voltage multiplied by the number of cells connected in series.

Note that care should be taken in calculating currents for voltages of periods less than one minute in duration. If multiple current levels exist within a minute (typically due to momentary loads), the lowest voltage occurs when the current is greatest. When that current is decreased, the voltage does not increase instantaneously as it responds more slowly due to the chemical response of the battery. In this case the low voltage value should be shown as the voltage for the balance of the minute consistent with the sizing methodology for momentary loads described in 4.2.3.

To determine the voltage profile for cells at other than 25 °C (77 °F) electrolyte temperature and/or less than 100% of rated capacity, multiply the current for each period during the duty cycle by the same correction factors used to size a battery per this recommended practice. For example, to predict the performance of a cell at 15.6 °C (60 °F) and 80% of its rated capacity, multiply each current value in the duty cycle by the temperature correction factor and the aging factor to determine the cell voltage. Similarly, if the cell performance (in amperes per positive plate) is not a constant value for all sizes of a given type of cell, the current for each period during the duty cycle should be adjusted by using the appropriate correction factor as provided by the battery manufacturer.

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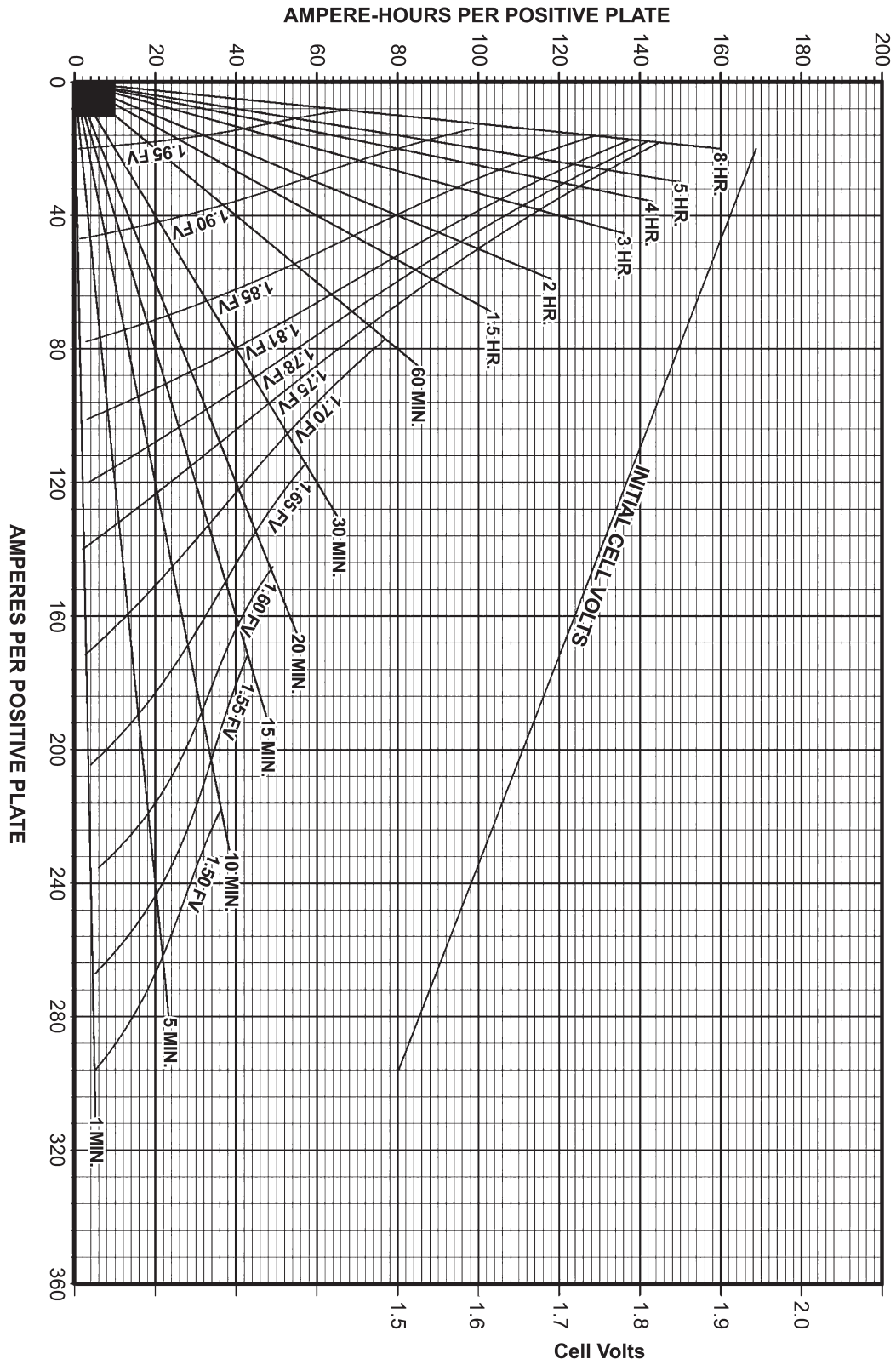

Figure B.1—Discharge characteristics of ABC-type cell (Fan Curve)

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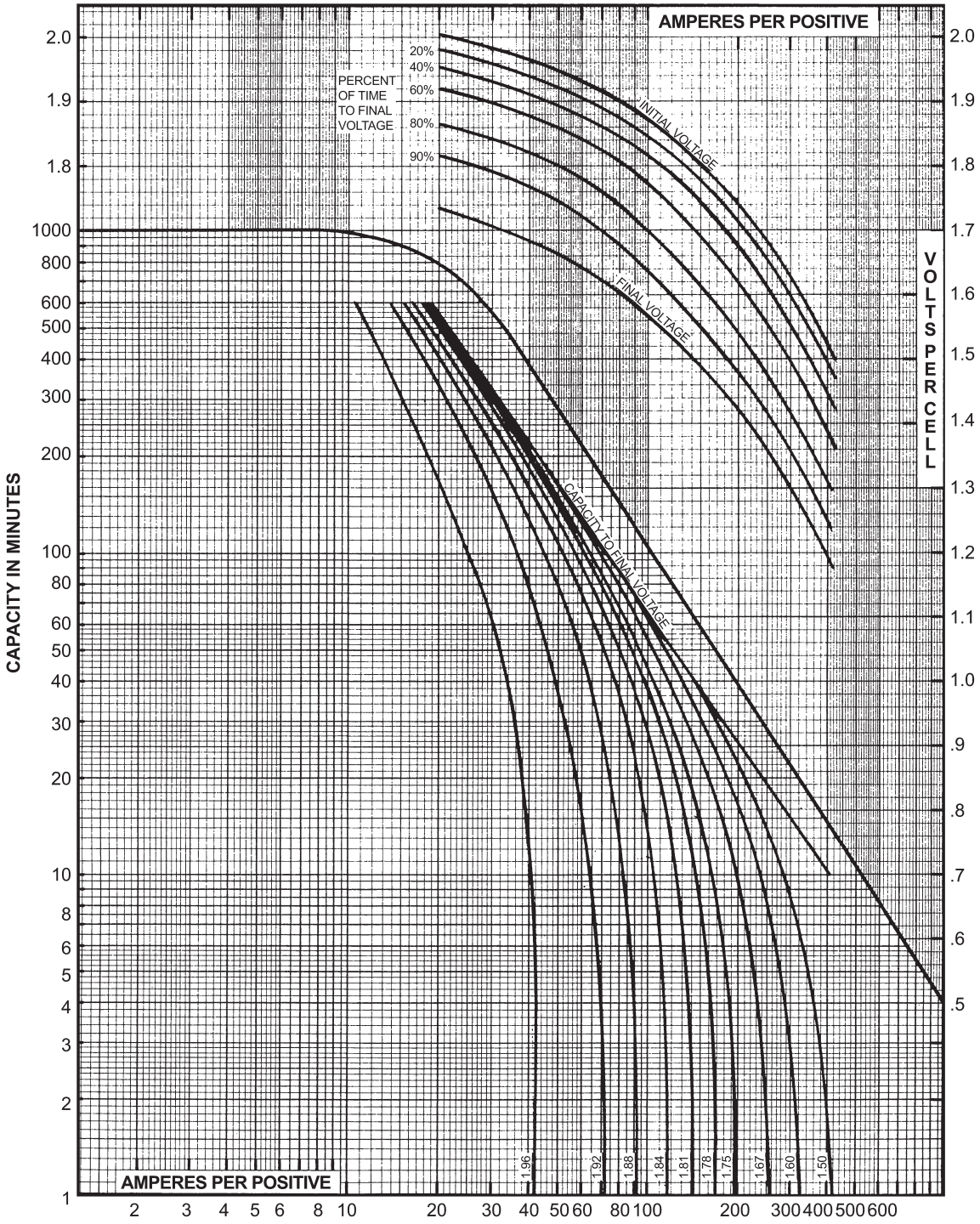

Figure B.2—Discharge characteristics of DEF-type cell (S curve)

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B.3 Sample calculations

B.3.1 Example number 1 (using “fan” curves)

A sample voltage calculation for an assumed cell type, duty cycle, and conditions follows:

Cell type:	ABC, 10 positive plates
Duty cycle:	700 A for 1 min, then 500 A for 59 min, then 150 A for 180 min
Conditions:	Electrolyte temperature: 25 °C (77 °F)
Cell capacity:	100% of rated capacity

The average cell voltage at the time where the voltage is to be determined is found on the “fan” curve at the intersection of the following:

a) the cumulative total ampere-hours per positive plate

b) the ampere-hours per positive plate. When necessary, interpolate between adjacent “final volt” lines

Step 1

Using the ABC discharge characteristic curves (Figure B.1), determine cell volts during the first 1 min load: 700 A for 1 min = 11.67 Ah increment

11.67 Ah cumulative, or $\frac{11.67}{10} = 1.17\ \text{Ah/positive plate cumulative}$

$$\frac{700\ \text{A}}{10\ \text{positive plates}} = 70\ \text{A/positive plate}$$

From the curve, a 70 A/positive plate intersects a 1.17 Ah/positive plate (at the abscissa line) at approximately the 1.86 V/cell.

The initial (only) voltage can also be obtained by projecting a 70 A/positive plate vertically to the “initial volts” line where 1.86 V is also read. Thus, the first load drops the battery voltage to the 1.86 V/cell for the entire minute.

Step 2

Because the second load is less than the first load, the cell terminal voltage rises upon its initiation. To determine the recovery voltage: 500 A for 0 additional minutes is a 0 Ah increment, 11.67 Ah cumulative, or 1.17 Ah/positive plate cumulative.

$$\frac{500\ \text{A}}{10\ \text{positive plates}} = 50\ \text{A/positive}$$

On the curve, 50 A/positive plate intersects a 1.17 Ah/positive plate (at the abscissa line) at approximately 1.89 V/cell.

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Step 3

To determine the voltage at the end of 30 total minutes: 500 A for 29 additional minutes is a 241.67 Ah increment, 253.34 Ah cumulative, or 25.34 Ah/positive plate cumulative.

$$\frac{500\ \text{A}}{10\ \text{positive plates}} = 50\ \text{A/positive}$$

On the curve, a 50 A/positive plate intersects a 25.33 Ah/positive plate at approximately 1.88 V/cell.

Step 4 through Final

The preceding process is repeated for each step to determine the cell voltage at each point in the duty cycle. The results for this example are tabulated in Table B.1 and the voltage/time profile is shown in Figure B.3.

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Table B.1—Cell voltage over time using "fan" curve

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Load (A)	Time interval (min)	Cumulative discharge time (min)	Incremental Ah removed	Cumulative Ah removed	Cumulative Ah per positive plate (5)/10	Load amperes per positive plate (1)/10	Intersection of (6) and (7) (V/cell)
700	0	0	0	0	0	70	1.86
700	1	1	11.67	11.67	1.17	70	1.86
500	0	1	0	11.67	1.17	50	1.89
500	29	30	241.67	253.34	25.33	50	1.88
500	30	60	250	503.34	50.33	50	1.86
150	0	60	0	503.34	50.33	15	1.94
150	30	90	75.0	578.34	57.83	15	1.94
150	30	120	75.0	653.34	65.33	15	1.93
150	30	150	75.0	728.34	72.83	15	1.93
150	30	180	75.0	803.34	80.33	15	1.92
150	30	210	75.0	878.34	87.83	15	1.92
150	30	240	75.0	953.34	95.33	15	1.90

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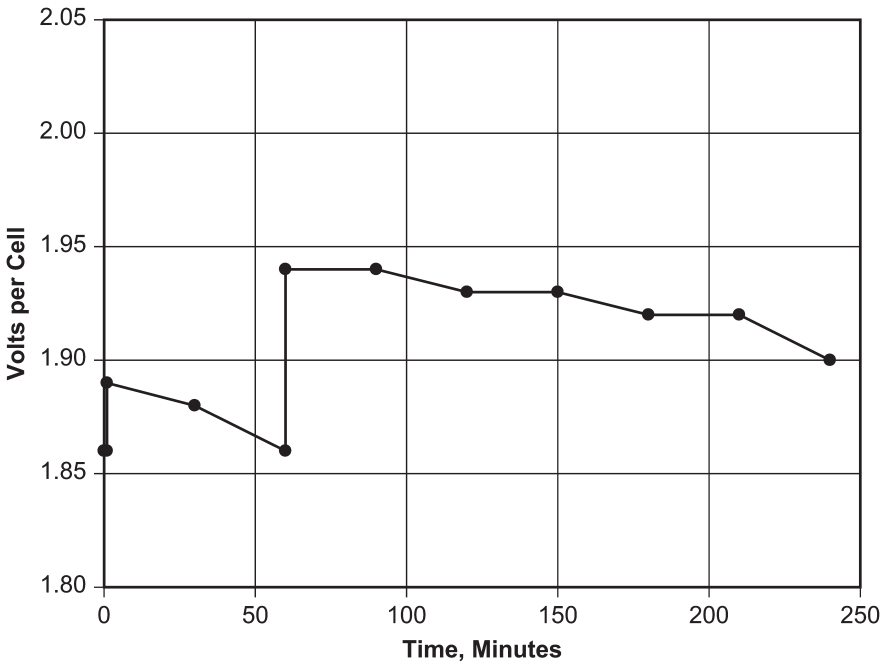

Figure B.3—Calculated voltage/time profile from "fan" curves

B.3.2 Example number 2 (using "S" curves)

A sample voltage calculation for an assumed cell type, duty cycle, and conditions follows:

Cell type: DEF-21, 10 positive plates and characteristics as shown in Figure B.2

Duty cycle: 1000 A for 1 min, then
700 A for 29 min, then
300 A for 180 min

Conditions: Electrolyte temperature: 25 °C (77 °F), TF = 1.00
80% capacity [1.25 aging factor (AF) = 1.25]
Design margin (DM) = 1.00
Cumulative correction factor = TF × AF × DM = 1.00 × 1.25 × 1.00 = 1.25

Calculations: Refer to Table B.2 and Figure B.2.

Column A: This is the time period in minutes. Example: 1 min to 30 min (29 min of discharge).

Column B: This is the time interval for this part of the calculation. Example: The time interval is zero at the beginning of any period. The example only calculates the value at the beginning and end of each period. Intermediate values can be calculated.

Column C: This is the duty cycle in amperes for the period. Example: 700 A for 1 min to 30 min.

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Table B.2—Cell voltage over time using "S" curve

A	B	C	D	E	F	G	H	I	J	K
Time period	**Time interval (min)**	**Duty cycle (A)**	**Corrected amperes (Col. C × correction factors)**	**A-min increment cumulative (Col. D × Col. B)**	**A-min/ positive plate incremental cumulative (Col. E/ positive plates)**	**A/positive plate (Col. D/ positive plates)**	**Time to final voltage in min (from "S" curve)**	**A-min/ positive plate A/positive plate × time to final voltage (Col. G × Col. H)**	**% Discharge (Col. F cumulative/ Col. I) × 100**	**V/ cell (from "S" curve)**
				cumulative value	**cumulative value**					
0 to 1 min	0	1000	1250	0 0	0 0	125	—	—	0	1.815
	1	1000	1250	1250 1250	125 125	125	50	6250	2	1.81
1 to 30 min	0	700	875	0 1250	0 125	87.5	85	7437.5	1.68	1.865
	29	700	875	25 375 26 625	2537 2662	87.5	85	7437.5	35.8	1.82
30 to 210 min	0	300	375	0 26 625	0 2662	37.5	270	10 125	26.3	1.91
	180	300	375	67 500 94 125	6750 9412	37.5	270	10 125	92.9	1.75

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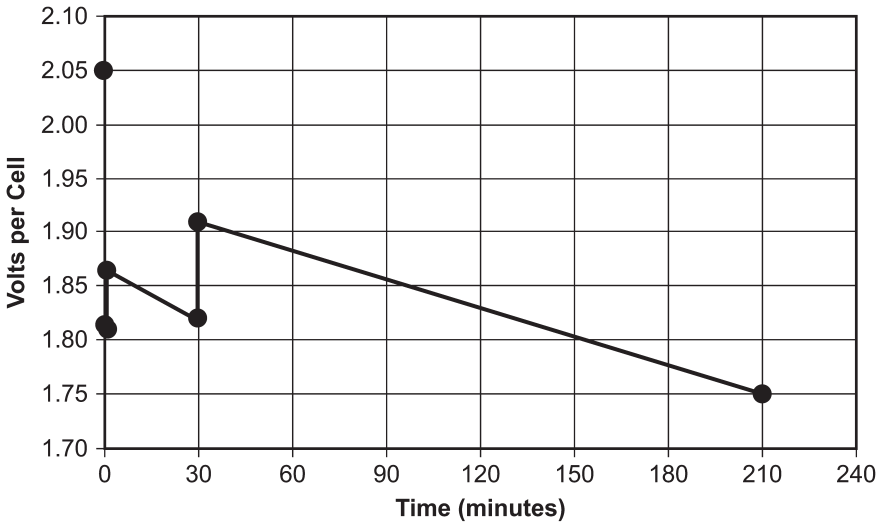

Figure B.4—Calculated voltage/time profile from "S" curves

Column D: Corrected amperes to account for aging, temperature, and design margin.
Example: 700 × 1.25 = 875 A.

Column E: Ampere-minutes in both incremental and cumulative values. Example: The incremental ampere-minutes for the 29 min interval is 875 × 29 = 25375. The cumulative ampere-minutes is the previous cumulative total (1250) plus the incremental value (1250 + 25375 = 26625 A-min).

Column F: Ampere-minutes per positive plate in both incremental and cumulative values. Example: Take the values from Col. E and divide by the number of positive plates. 25375/10 = 2537 incremen-tal ampere-minutes per positive plate and 26625/10 = 2662 cumulative ampere-minutes per positive plate.

Column G: Amperes per positive plate, which is Col. D divided by the number of positive plates.
Example: 875/10 = 87.5 A per positive plate.

Column H: Time to final voltage is determined from the "S" curves. Example: Time to final voltage is read at 87.5 A/positive plate on the *x* axis up to the "capacity to final voltage" curve. The needed value is then read from the left *y* axis and is 85 min. The "capacity to final voltage" curve is at the extreme right-hand side of the 1.67 V line.

Column I: This is ampere/positive plate times the time to final voltage.
Example: Multiply Col. G by Col. H (87.5 × 85 = 7437.5 A-min per positive plate).

Column J: Percent of discharge is the cumulative ampere-minutes/positive plate divided by ampere/positive plate times time to final voltage.
Example: This is Col. F (lower value) divided by Col. I (2662/7437.5 = 0.358 or 35.8%).

Column K: Volts per cell is the expected cell voltage at the calculated point in time for the conditions specified as determined from the "S" curves. Example: The value is determined by taking the discharge rate in ampere/positive plate on the *x* axis and projecting up to the percent of discharge curve and then reading the cell voltage at the right *y* axis (87.5 A and 35.8% discharge—interpolate between the 20% and 40% curves and read the value at the right *y* axis of 1.82 V/cell).

The results for this example are tabulated in Figure B.2, and the voltage/time profile is shown in Figure B.4.

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Annex C

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Consideration of cell types

Lead-acid batteries share many similarities in construction and operation, but there are differences in design that should be considered when selecting a battery to achieve the best possible fit for the application.

IEEE Std 1184-2006 is a comprehensive UPS guide and should be used as a reference for comparison of different battery types. This annex is a supplement to IEEE Std 1184-2006.

The dc system designer should recognize that some lead-acid batteries are designed for low-rate, long-duration loads and that other batteries are better for high-rate, short-duration loads so the selection of the battery type is dependent on the duty cycle. Generally, some differences between the battery types would be number and thickness of the plates, separator material and thickness, distance between the plates, and available sediment space among other factors.

The dc system designer should be aware of pitfalls that could result from the selection of the wrong battery type, such as the application of a battery designed for low-rate, long-duration loads that might not have a 1-min rate sufficient to allow the battery to operate needed momentary loads. Conversely, application of a battery that is designed for high-rate, short-duration loads may have short-circuit capability that exceeds the capability of the system and the installed protective devices.

Table C.1 is typical of a series of battery types from a single manufacturer. The type listed as C would be representative of a battery for communication service, type S would be representative of a battery for switchgear service, and type U would be representative of a battery for UPS service. As mentioned in 6.4.3, K_t is the ratio of ampere-hour capacity (at a standard time rate, at 25 °C and to a standard minimum cell voltage) of a cell, to the amperes that can be supplied by that cell for t min at 25 °C and to a standard minimum cell voltage. As such, a battery with a higher K_t would be less efficient at higher rates.

Table C.1—Representative battery types

Type	80-h capacity	1-min rate	K_t
C	1220 Ah	924 A	1.32
S	1120 Ah	1190 A	0.94
U	1168 Ah	2677 A	0.43

Each of the batteries listed in Table C.1 could be used in any application if the battery's capability meets the duty cycle. But the design engineer should be aware that significant differences exist in battery types and a misapplication can result in the purchase of a larger battery than is really needed. Even more significant, a battery could be specified that would not be able to supply all of the loads within the duty cycle.

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Annex D

(informative)

Constant power and constant resistance sizing

D.1 Overview

Much of today's equipment requires constant power. Constant power loads differ from constant current in that as the battery voltage decays, the current required increases, as shown in Figure D.1.

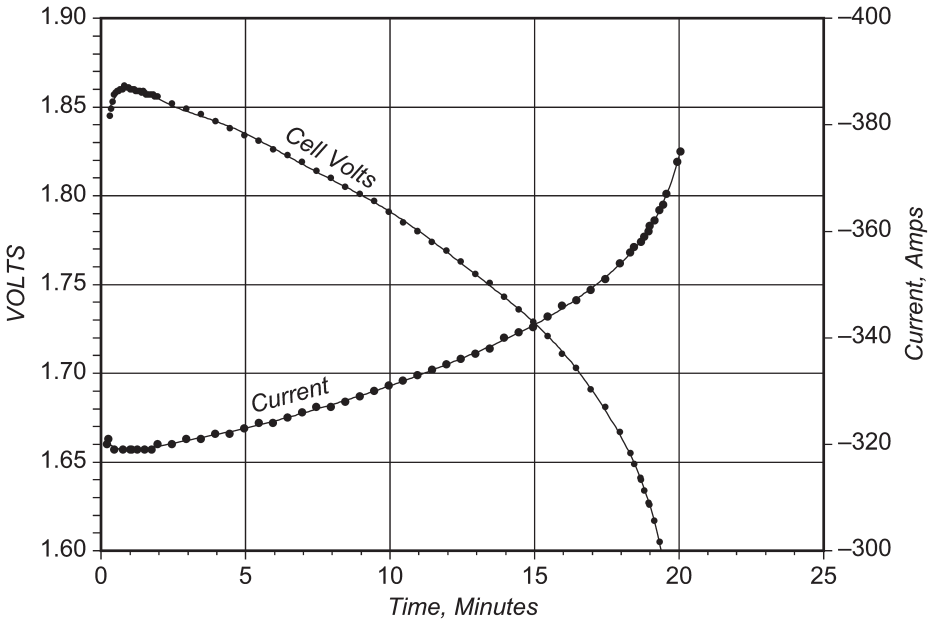

Figure D.1—Voltage versus time constant power load

For many battery models, constant power fan curves or tables are available from the manufacturer. The same general principles apply for data collection and fan curve generation as for constant current fan curves or tables. The main differences are as follows: the type of discharge performed to gather the required data and the change of units from amperes per positive plate to watts per positive plate and ampere-hours per positive plate to watt-hours per positive plate. Figure D.2 shows a typical constant power discharge characteristic curve.

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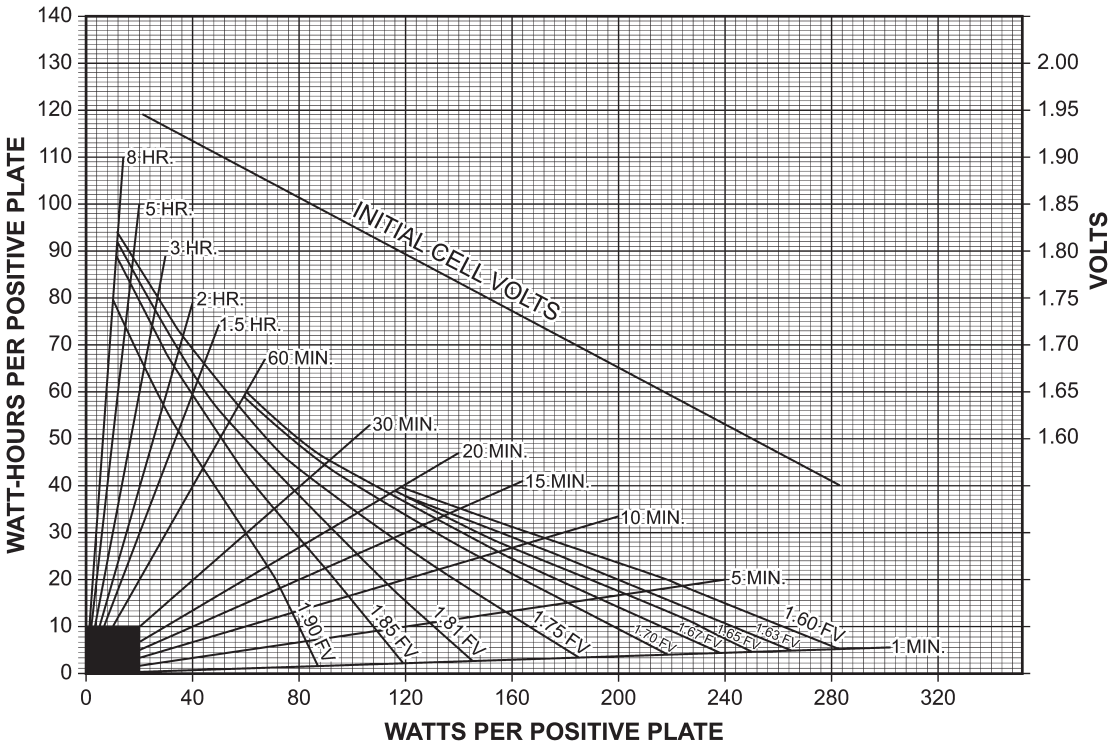

Figure D.2—Constant power discharge characteristic curve cell type: ABC

D.2 Examples

For the following examples, factors for aging, temperature, and design margin are neglected for simplicity.

D.2.1 Example number 1

Determine the battery required to provide 250 kW for 15 min with a battery terminal voltage window of 140 V to 100 V by calculating the following:

a) Number of cells = 140 V/2.33 VPC = 60 cells

b) Minimum cell voltage = 100 V/60 cells = 1.67 VPC

c) Load per cell = 250 kW/60 cells = 4.167 kW per cell

Assume a charging requirement of 2.33 V per cell (VPC).

From the sample sizing chart (Table D.1), determine (under the columns for 15 min and 1.67 VPC) the kW per cell capability that meets the 4.167 kW per cell requirement.

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Table D.1—Sample sizing chart—values shown in kW per cell

1.67 Final volts	Minutes to final volts								
ABC cell type	5	10	12	14	15	16	18	20	30
ABC-17	2.787	2.409	2.275	2.163	2.120	2.069	1.981	1.895	1.559
ABC-19	3.135	2.709	2.560	2.434	2.386	2.327	2.229	2.132	1.754
ABC-21	3.484	3.010	2.844	2.704	2.650	2.585	2.477	2.369	1.949
ABC-23	3.784	3.276	3.110	2.945	2.886	2.816	2.697	2.297	2.132
ABC-25	4.072	3.535	3.357	3.182	3.117	3.042	2.914	2.789	2.307
ABC-27	4.354	3.781	3.590	3.413	3.344	3.262	3.126	2.989	2.484
ABC-29	4.666	4.044	3.839	3.650	3.576	3.489	3.343	3.197	2.657
ABC-31	4.974	4.302	4.085	3.883	3.805	3.712	3.556	3.401	2.827
ABC-33	5.278	4.560	4.330	4.116	4.034	3.935	3.771	3.606	2.997
ABC-35	5.581	4.811	4.568	4.342	4.255	4.051	3.977	3.803	3.161
ABC-37	5.878	5.057	4.802	4.564	4.473	4.364	3.181	3.998	3.322
ABC-39	6.173	5.305	5.037	4.788	4.692	4.577	4.386	4.195	3.486

The ABC-33 at 4.034 kW per cell is close, but the actual minimum cell size required is type ABC-35. The rating for this cell is 4.255 kW per cell, which is greater than the 4.167 kW per cell requirement.

If individual cells of sufficiently large capacity for the specified load are not available, then two or more strings of equal numbers of series connected cells should be connected in parallel to obtain the necessary capacity. The capacity of such a battery is the sum of the capacities of the strings. (Additionally—although rare—certain situations occur where it is more economical to provide parallel strings of multicell units instead of one string of large, single-cell units.)

D.2.2 Example number 2

Instead of a 250-kW load, the requirement is for a 300-kW load. The required cell capability is now 300 kW/60 cells = 5.00 kW per cell, but from the sizing chart, the largest cell is only capable of 4.692 kW; therefore, parallel battery strings shall be provided.

Because the largest ABC cell can provide 4.692 kW, another ABC-39 in parallel would double the capability to 9.384 kW. While this would be more than adequate, this is far larger than the 5.00 kW per cell required. Two parallel strings of a smaller cell is adequate.

A 5.00 kW per cell requirement requires a minimum of 2.50 kW per cell for each parallel string. From the sizing charts, the ABC-21 at 2.65 kW per cell meets this requirement. Therefore, the minimum battery size required is two parallel strings of 60 cells per string of type ABC-21 cells.

D.3 Conversion from constant power loads to constant current

Loads applied to the battery are normally categorized as constant power, constant resistance, or constant current. The designer should review each system to verify that all possible loads and their variations have been included.

The battery voltage decreases as the battery discharges (as does the voltage at the loads). The amount by which the battery voltage decreases depends on the battery design and the load placed on the battery. For constant power loads, the current increases with a voltage decrease. Inverters and dc/dc power supplies are

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usually constant power; they are internally regulated to maintain a constant output voltage as the input voltage decreases. As a result, the dc input current increases as the input voltage decreases. If the constant power load is remote from the battery, the voltage drop increases because of the cable resistance and the resulting input current is higher. It is desirable to consider the increase in load current as battery voltage declines. This can be calculated as follows:

$$I_{\text{AVG}} = \frac{P}{EV_{\text{AVG}}}$$

where

I_{AVG} is the average discharge current (A) for the discharge period
P is the discharge load (W)
V_{AVG} is the average discharge voltage for the discharge period

Because the voltage profile for a particular battery is typically unknown, an alternative method for calculating the current is simply to divide the power by the end voltage. This method results in a conservative estimate of current (minimum volts, maximum amperes). Thus,

$$I_{\text{MAX}} = \frac{P}{EV_{\text{MIN LOAD}}}.$$

where

I_{MAX} is the discharge current at the end of the discharge period
P is the discharge load (W)
$V_{\text{MIN LOAD}}$ is the minimum battery voltage minus voltage drop

Example: For a 24 cell battery operating in a nominal 48 V system with a minimum battery voltage of 42 V and a voltage drop from the battery to the load of 2 V, a constant power load of 5000 W discharges the battery at a rate no greater than

$$I_{\text{MAX}} = \frac{5000\ \text{W}}{40\ \text{V}} = 125\ \text{A}$$

It is also important to be able to work the equations from having load data in wattage. When equipment loads are specified in watts but no constant power load bank is available, then conversion from watts to amperes is necessary. This is done by means of an average voltage curve, as explained subsequently. Because watts = volts × amps, it follows that average watts = average volts × average amperes. Because a constant power load on a battery is unvarying, watts = average volts × average amperes. If the average voltage is known for a particular discharge span and end voltage, the average current can be calculated.

Figure D.3 shows a typical constant current voltage versus time curve with the calculated average voltage during the discharge. Using this graph, the average voltage for any final voltage can be ascertained for this discharge. Listed in Table D.2 are the final volts, time to final volts, and calculated average volts for a 7-h discharge.

Table D.2—7 h discharge data

Final volts	Time to final volts	Average volts
1.75	7.10 h	1.912
1.80	6.71 h	1.917
1.85	6.04 h	1.929
1.90	4.64 h	1.944

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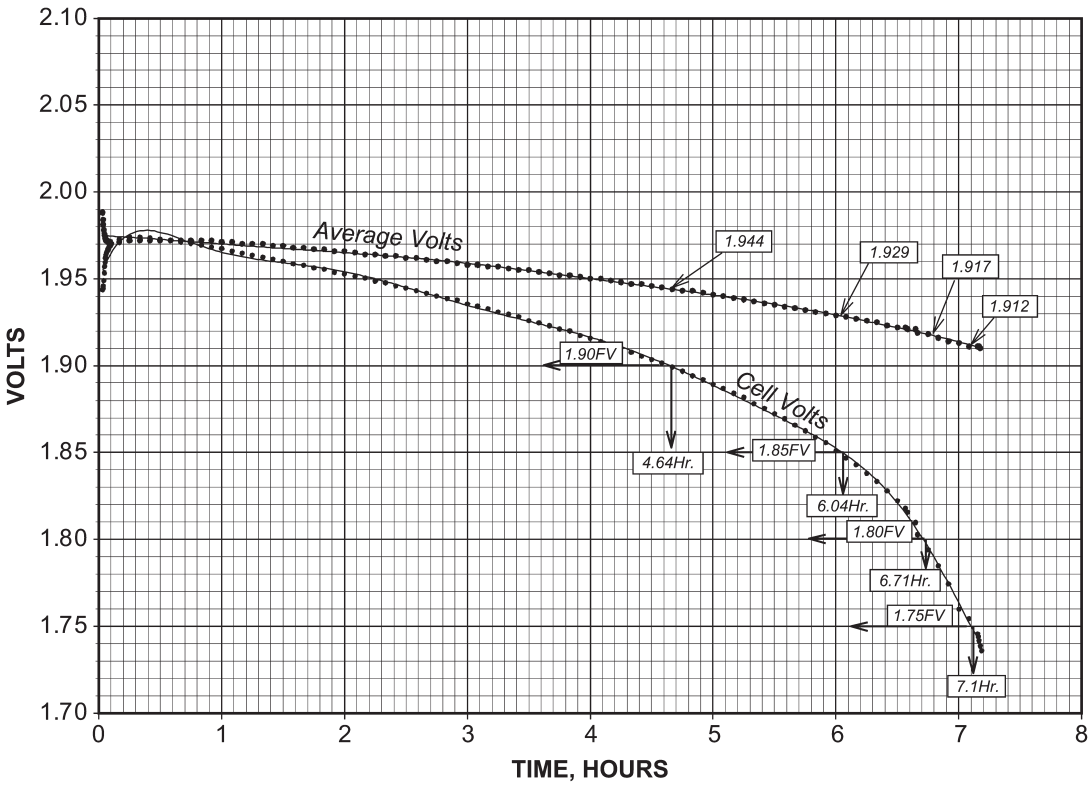

Figure D.3—Typical voltage versus time curve with calculated average volts cell type: ABC

The average voltage is then calculated for every constant current discharge to the required final voltage. All the average voltages and the time to the average volts are then plotted on a separate curve. Figure D.4 shows average voltages for discharges from 1 min to 480 min to various final voltages. The data points are curve fit. The finished curve appears as in Figure D.5.

Using the curve:

From the previous 250 kW example load, with a 15-min duration and a minimum voltage of 1.67 VPC, the average voltage is determined to be 1.73 VPC from Figure D.5. The average discharge current is then calculated:

$$\frac{\text{watts (load on battery)}}{\text{number of cells} \times \text{average volts}} = \text{average amps (discharge current)}$$

$$\frac{250\ 000\ \text{(load on battery)}}{(60 \times 1.73\ \text{VPC})} = 2408.5(\text{average amps})$$

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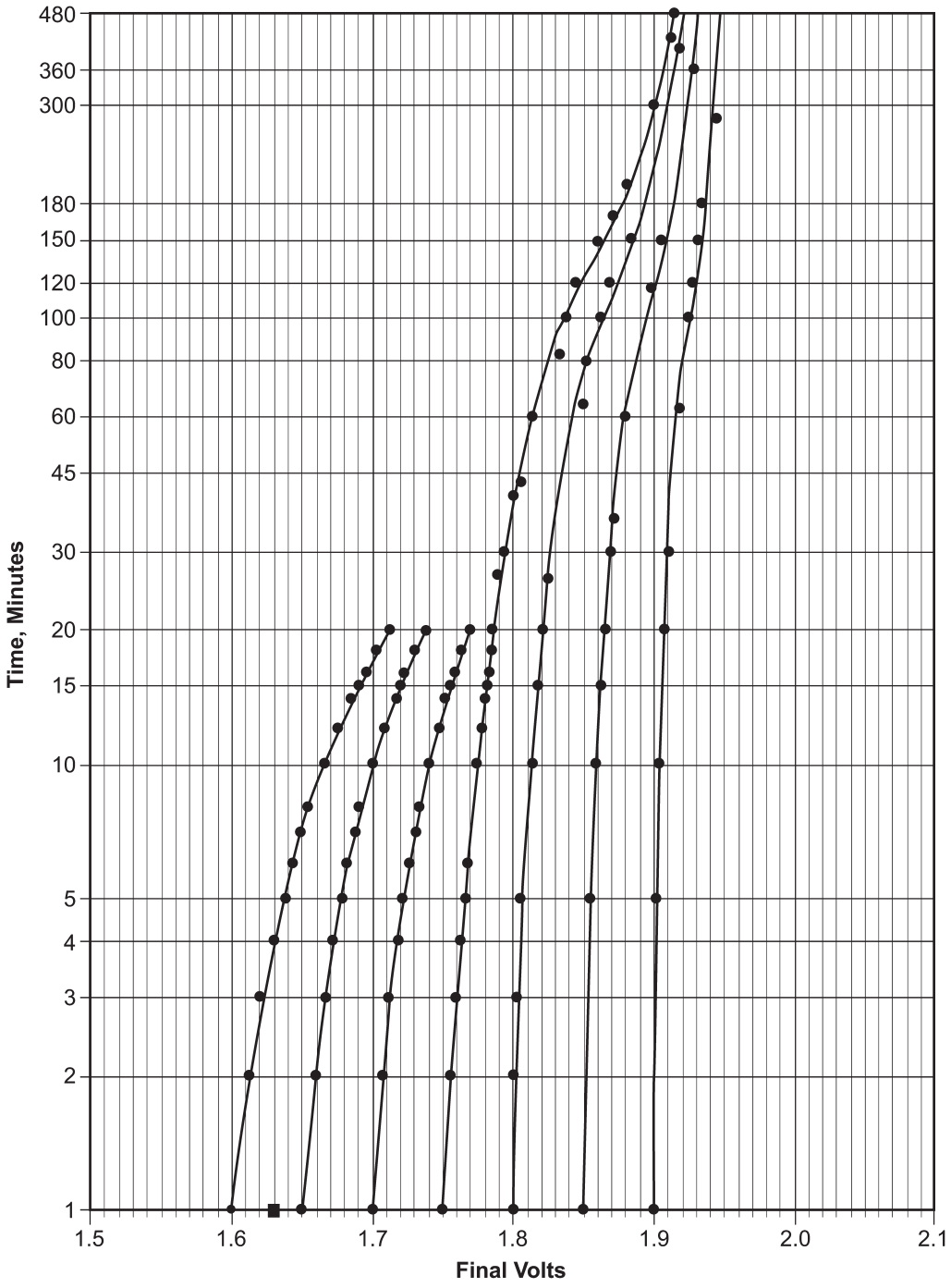

Figure D.4—Cell type: ABC-33 average volts to final volts—curve fit

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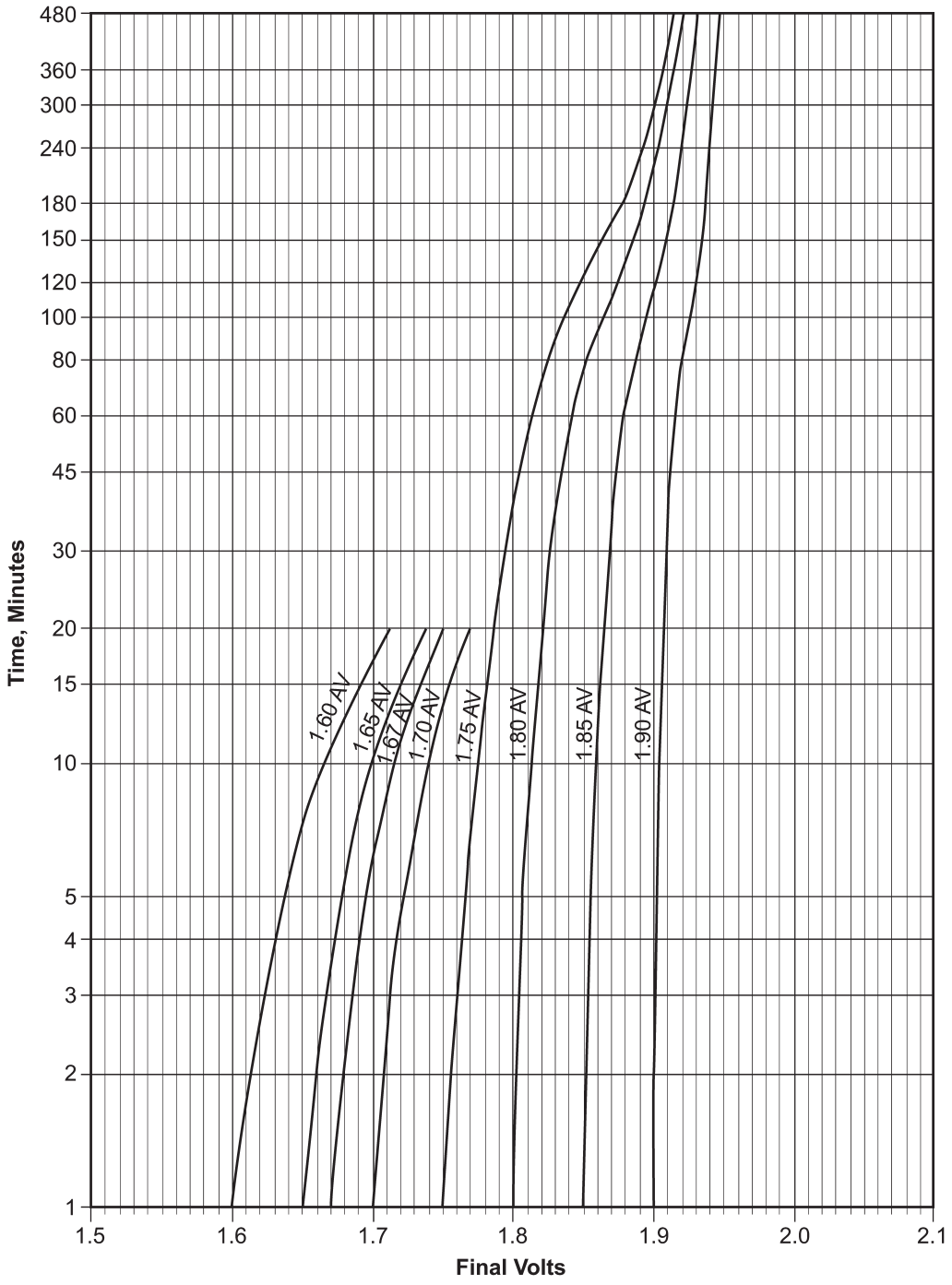

Figure D.5—Cell type: ABC-33 average volts to final volts—final

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D.4 Conversion from constant resistance loads to constant current

For constant resistance loads, current decreases as the voltage decreases. DC motor starting, emergency lighting, relays, contactors, and indicating lights are usually constant resistance. A constant resistance load is conservatively estimated as a constant current load as follows:

$$I_{MAX} = \frac{V_{OC}}{R} \text{ or } I_{MAX} = \frac{W_R}{V_{OC}}$$

where

V_{OC} is the battery open circuit voltage (typically 0.85 + nominal specific gravity)
R is the resistance
W_R is the rated power value

As with constant power loads, the load current can be calculated using the average battery voltage. The system voltage drop to the loads can also be considered.

However, if significant motor starting currents are required from the battery at the beginning of the cycle, the battery voltage should be calculated from initial data using an estimate of the inrush current, and then checking that the initial voltage supports that level of current, iterating the level of current and voltage until a satisfactory solution is obtained.

D.5 Other considerations

D.5.1 UPS

UPS power ratings are quoted in volt-amperes (VA) and/or watts. The rating in watts is equal to the rating in volt-amperes multiplied by the power factor. The battery load for sizing purposes is the UPS output rating in watts divided by the efficiency of the inverter. The efficiency should be based on rated UPS output. Therefore, UPS output power rating in watts = UPS output in volt-amperes × power factor nominal battery load = UPS output power/inverter efficiency.

Temperature, aging, and design margin considerations should be addressed as described in 6.3.

D.5.2 DC motors

While motors are typically considered constant power loads, dc motors can be approximated as constant current. Within the normal battery voltage range, the flux is fairly constant in the motor. Modeling a dc motor as a constant current load is conservative if the voltage maintains the motor in saturation.

D.6 Summary

To size a battery properly for a constant power application, the following information is required:

a) The system voltage window. This allows a calculation of the number of cells and minimum cell voltage. Refer to the example provided previously.

b) The load in watts, kilowatts, or amperes imposed on the battery.

c) The length of time the battery must provide the load without falling below the minimum voltage.

d) The minimum temperature, aging allowance, and design margin at which the battery is expected to perform.

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Annex E

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Development and use of battery discharge curves

E.1 Overview

This annex describes the construction and use of battery discharge characteristic curves. The actual methodology involves multiple discharges with multiple cells at a controlled temperature approximating 77 °F. The average voltage versus time profile for each discharge is determined and then derated by a statistical measure, usually 2.6 or 3 sigma, to allow for manufacturing variability and thus assure 100% compliance to the products' nominal ratings. The product ratings are then verified by testing on factory production strings against the proposed rates.

This process is described in greater detail in E.2 and E.3.

E.2 Discharge curve fundamentals

A discharge characteristic curve is used to size batteries, and to experienced users, it is the most important tool.

Before interpreting this curve data becomes second nature, the curve itself must be understood: how the data were obtained, how it works, and ultimately, how to make it work for you.

The fundamentals about these curves, once learned, apply to any characteristic curve.

E.2.1 How the data was obtained

A typical characteristic curve (Figure E.1) has a myriad of straight lines radiating out from a common point, with a series of curving diagonal lines crossing their path. Even the coordinates sound similar enough to be confusing: amperes per positive plate on the horizontal (*x* axis) and ampere-hours per positive plate on the vertical (*y* axis). At the top, there is something labeled an initial volts line, which seems to bear no relationship at all to the others. To understand how to use the curve, the procedures about how a discharge characteristic curve is derived and plotted should first be understood.

First, a battery was discharge tested at several rates. The cell voltage was periodically monitored so the voltages can be plotted against time. An example of typical, plotted, test data is shown in Figure E.2.

Three important items of information from the test data are used in the construction of a discharge characteristic curve: the current at which the cell is discharged, the voltage of the cell at various times throughout the discharge, and the ampere-hours removed from the cell at various points in the discharge.

Next, data from the discharges is collated using a common reference value, so the information can be applied to any cell using the same size plates as the ones tested. This common value is the positive plate. Because the plates are connected in parallel within a cell, the rating of a cell is the rating of a positive plate times the number of positive plates in a cell.

A cell consists of positive and negative plates with one more negative plate than positive plates. The current is equally divided among the positive plates. For example, a battery with 33 plates has 16 positive plates and 17 negative plates. At a test rate of 320 A, the battery is discharged at 20 A per positive plate (320/16 = 20). Similarly, the capacities to various voltages can be shown as ampere-hours per positive plate.

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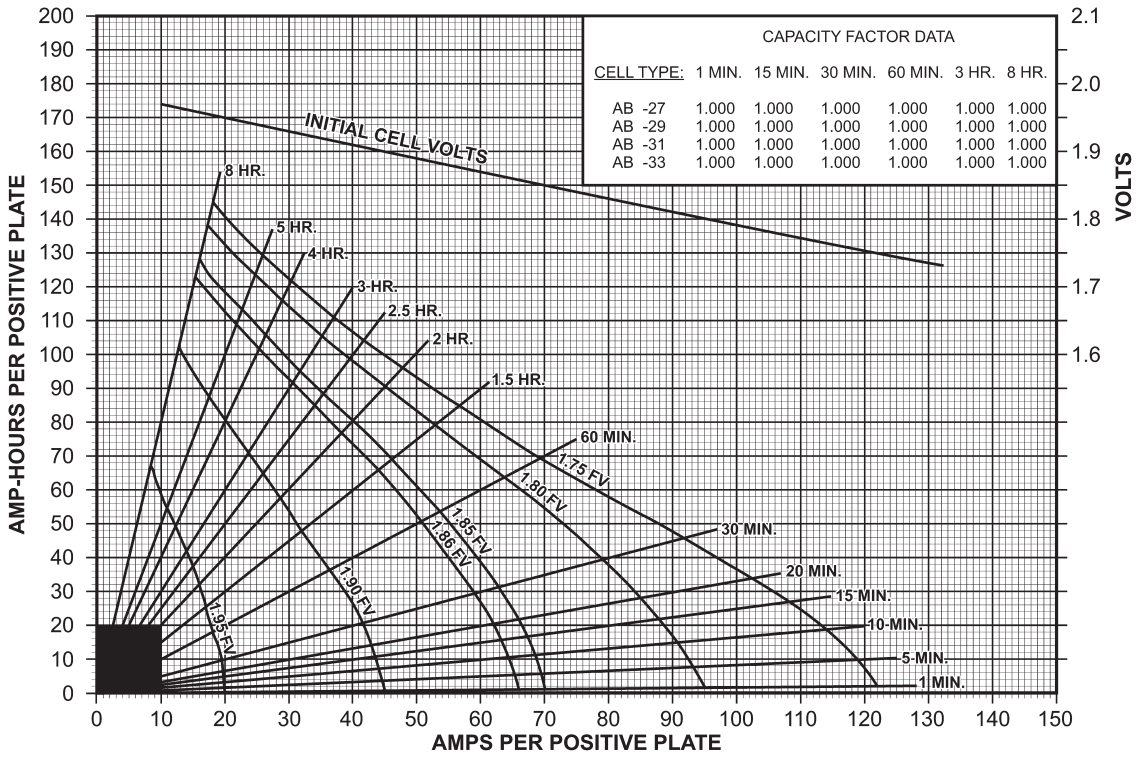

Figure E.1—Typical discharge characteristic curve for AB battery

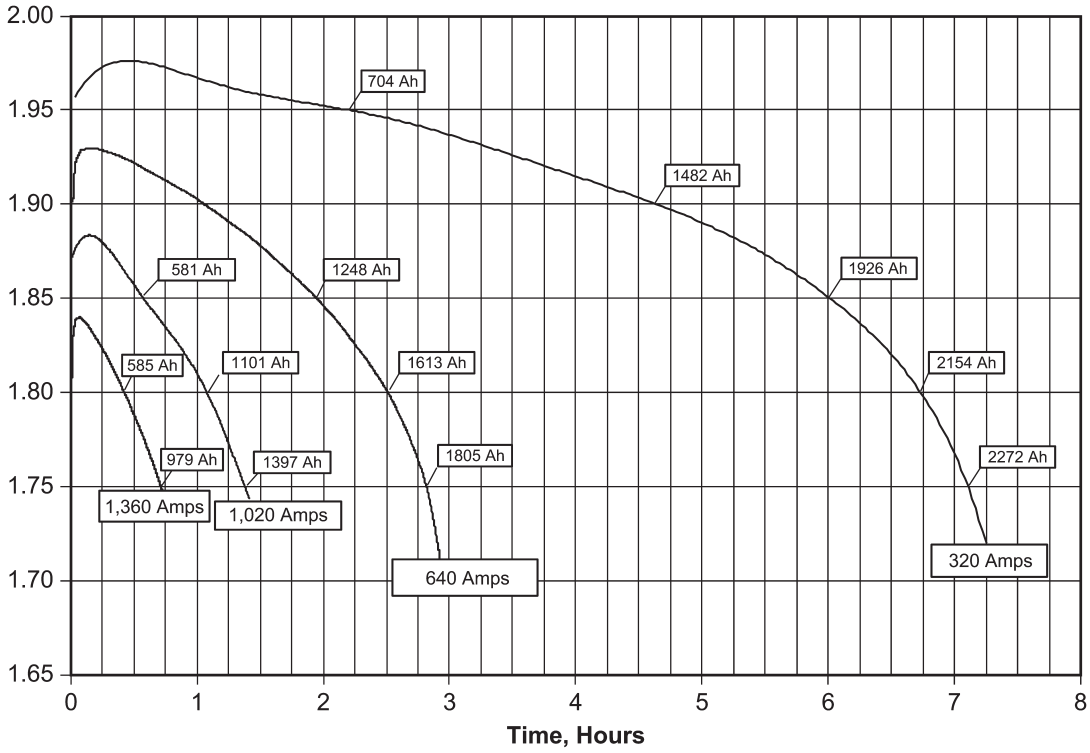

Figure E.2—Test data curve

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If a battery cell had but one positive plate, and over a particular time period was able to deliver 100 Ah, a cell with two positive plates would deliver 200 Ah and so on. Plates of the same polarity are always connected in parallel.

E.2.2 Plotting the data

Discharge rates

From the example test data in Figure E.2, if the cell voltage is 1.90 at 4.63 h into a 320 A discharge, 1482 Ah have been removed from the cell (320 A × 4.63 h). Also, the following occurs:

— At 1.85 V, 1926 Ah are removed (320 A × 6.01 h)

— At 1.80 V, 2154 Ah are removed (320 A × 6.73 h)

— At 1.75 V, 2272 Ah are removed (320 A × 7.1 h)

By calculating the ampere-hours per positive plate removed at various voltages and listing them opposite the equivalent amperes per positive plate value of the discharge rates, the discharge characteristics are ready for plotting (see Table E.1).

Table E.1—Preliminary test data

Final volts	Amperes per positive plate (16 positive plates)				
	20	40	63.8	85	
1.90	92.6	—	—	—	Ampere-hours per positive plate to final volts
1.85	120.4	78.0	36.3	—	
1.80	134.6	100.8	68.8	36.6	
1.75	142.0	112.8	87.3	61.2	

Discharge rate, which is expressed in amperes or amperes per positive plate, is distinct from discharge capacity, which is expressed in ampere-hours or ampere-hours per positive plate. As evident from Figure E.2, the higher the discharge rate, the less capacity is available before a particular voltage is reached. This is because the higher the discharge current (rate), the lower the cell voltage is at the beginning of the discharge, and because the conversion of chemical to electrical energy is less efficient, the end voltage is reached more quickly.

When the data in Table E.1 is transposed onto a graph (Figure E.3) with coordinates of amperes per positive plate and ampere-hours per positive plate, the discharge capability of the cell to a particular final voltage is characterized. While in this example only four data points are used, there is a way of interpolating where the final volt lines intercept the horizontal axis (0 Ah per positive plate). From the test data, note the battery delivers less and less capacity to a particular final voltage as the discharge current is increased. Logically then, there should eventually come a point where the discharge current is so great the cell voltage would drop immediately to the minimum voltage level. In other words, discharging the cell at this high current value would yield practically 0 Ah, because the final voltage would be reached as soon as the discharge was initiated. This is the initial voltage of a cell being discharged.

E.2.3 Initial volts

The initial voltage drop of a cell is primarily a function of its internal resistance and the discharge current. The voltage drop occurs at the positive electrode and is observed as a voltage drop by the cell. This effect is sometimes designated as the coup de fouet (stroke of the whip), which describes the initial fall and subsequent recovery of the voltage. As the discharge continues, the voltage again falls until the discharge is terminated. During momentary discharges, there is sometimes little difference between initial and final voltage.

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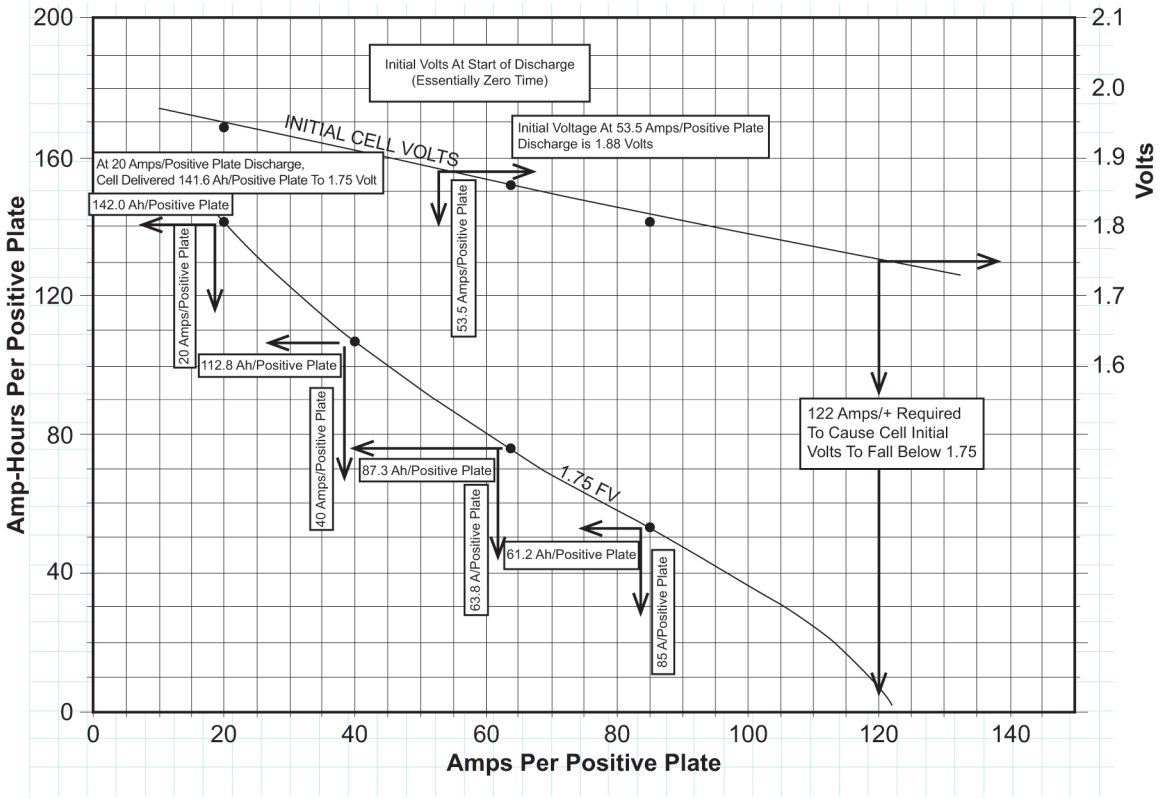

Figure E.3—Typical discharge characteristics to 1.75 V

When plotted as amperes versus initial volts, the points fall in a straight line. Four initial voltage points can be obtained from the original volts versus time discharge data plots of Figure E.2. Figure E.4 more clearly shows the coup de fouet at the various discharge rates. These points are recorded in Table E.2.

Table E.2—Initial voltage points

Ampere-hours per positive plate discharge current	Initial volts at discharge current
20.0	1.944
40.0	1.901
63.75	1.859
85.0	1.815

To plot the initial voltage data points, use the horizontal axis or amperes per positive coordinate and install another vertical axis or initial volts coordinate. Then, plot the initial voltages for the various loads and draw a straight line through the points. The line can be extended beyond 85 A per positive, the lowest voltage point determined by the example test, so it intersects the minimum final voltage needed on the curve. In this case, for 1.75 V, it intersects 122 A per positive plate (Figure E.3). Plotting the intercept on the horizontal axis provides the final data point needed to construct the 1.75 final voltage line. Final voltage lines for 1.80, 1.85, and 1.90 are done the same way (Figure E.5).

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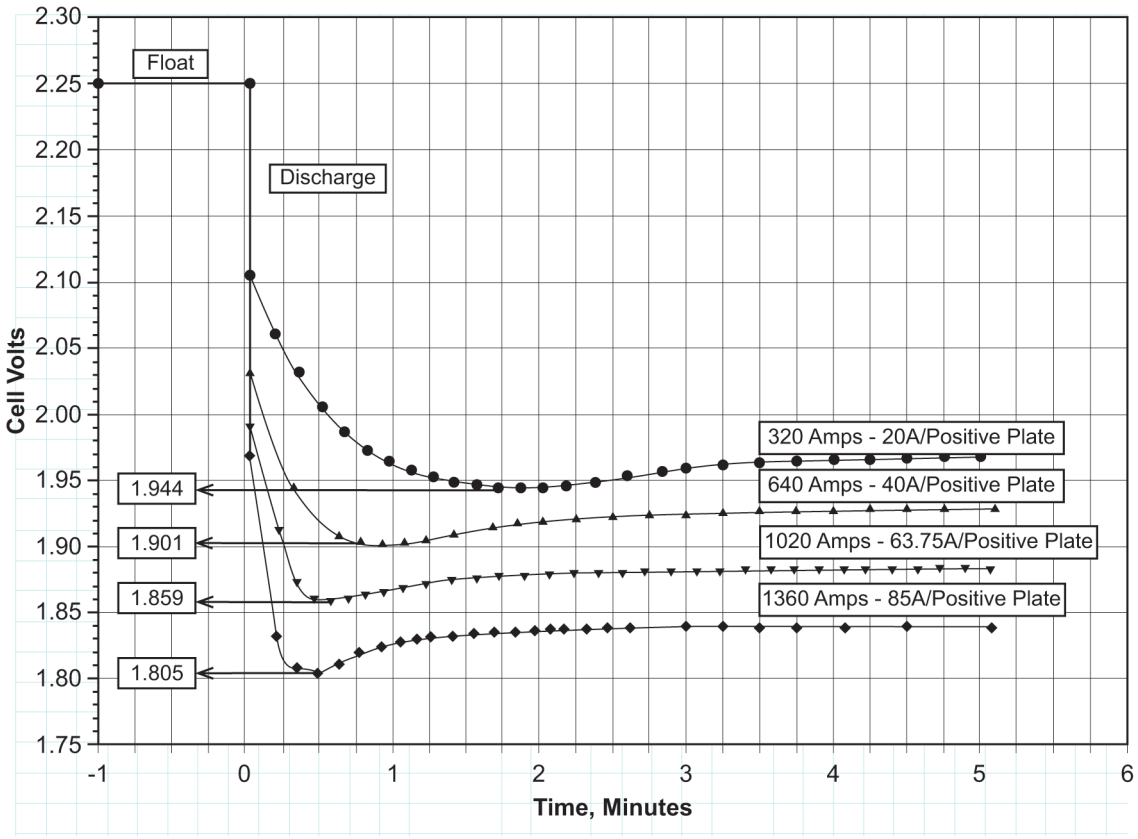

Figure E.4—Coup de fouet at various discharge rates for cell type ABC-33

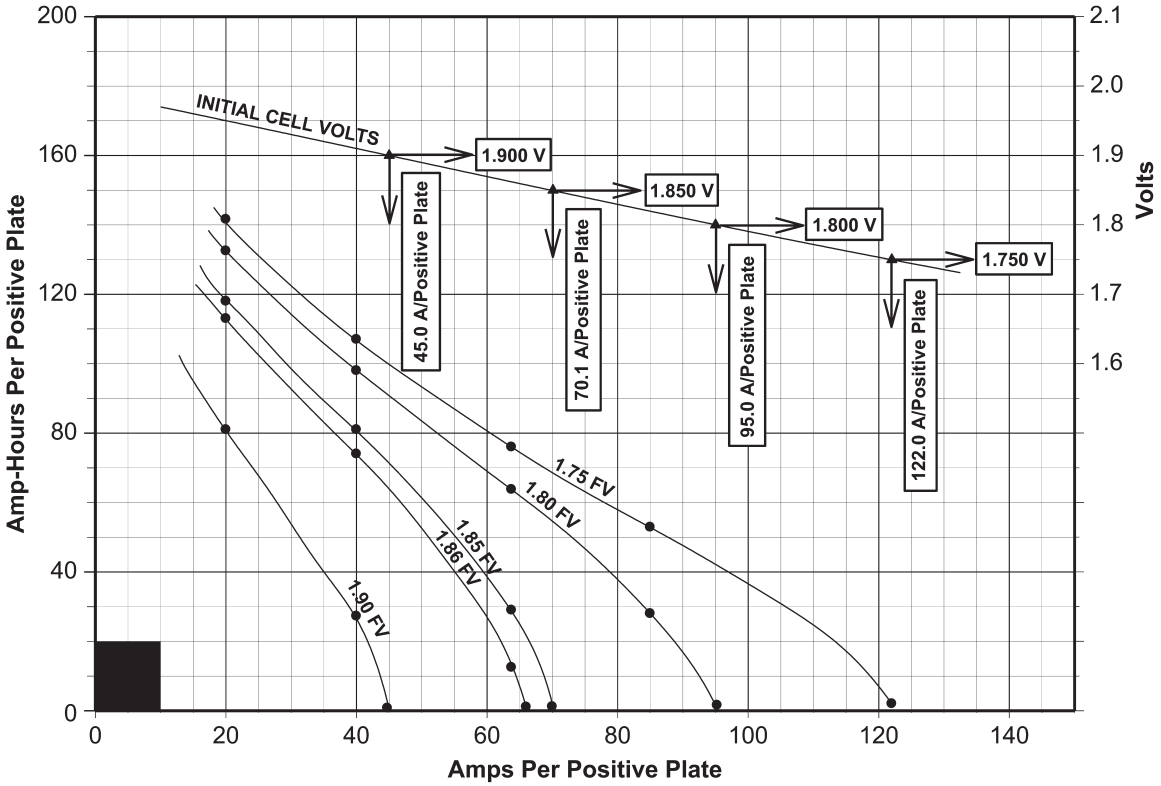

Figure E.5—Final voltage lines

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E.2.4 Time lines

After the final volt lines are plotted, another set of lines are added to plot the relationship of the coordinates (amperes versus ampere-hours). The time lines radiating from the origin on the graph are plotted according to discharge rate in amperes multiplied by time. For example, any battery discharged at 20 A per positive plate for 8 h has 160 Ah per positive plate removed. A line drawn from the origin, or zero, through the intersection of 20 A per positive plate and 160 Ah, is the eight-hour line. Any discharge characteristic line for a particular voltage crossing the eight-hour time line indicates a performance capability in ampere-hours or amperes, as shown by the value of these coordinates at the voltage line-time line intersect. The same rationale is used for the remaining time lines (Figure E.5). After all the lines are plotted, this graph is superimposed upon the voltage graph, resulting in the familiar characteristic curve (Figure E.6).

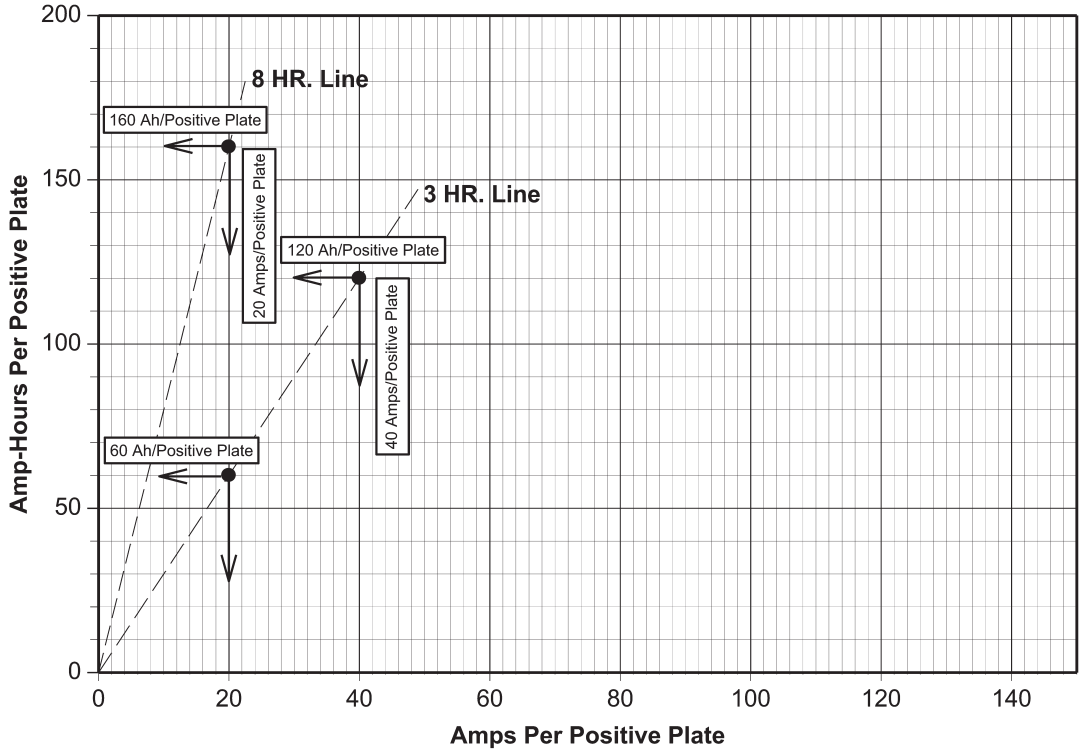

Figure E.6—Time lines

E.3 Using the characteristic curve

The characteristic curve (Figure E.7) allows the user to size batteries for any load or combination of loads for any reserve time and to any final voltage. Also, the performance of existing batteries can be predicted and voltage profiles for given loads or load duty cycles can be calculated. Note that the x axis values are the R_t values that can be used in the standard sizing calculation described in 6.5.

Three simple examples are given in E.3.1 through E.3.3.

NOTE—For simplicity, these examples do not consider the margins (design, aging, or temperature) required by this standard.

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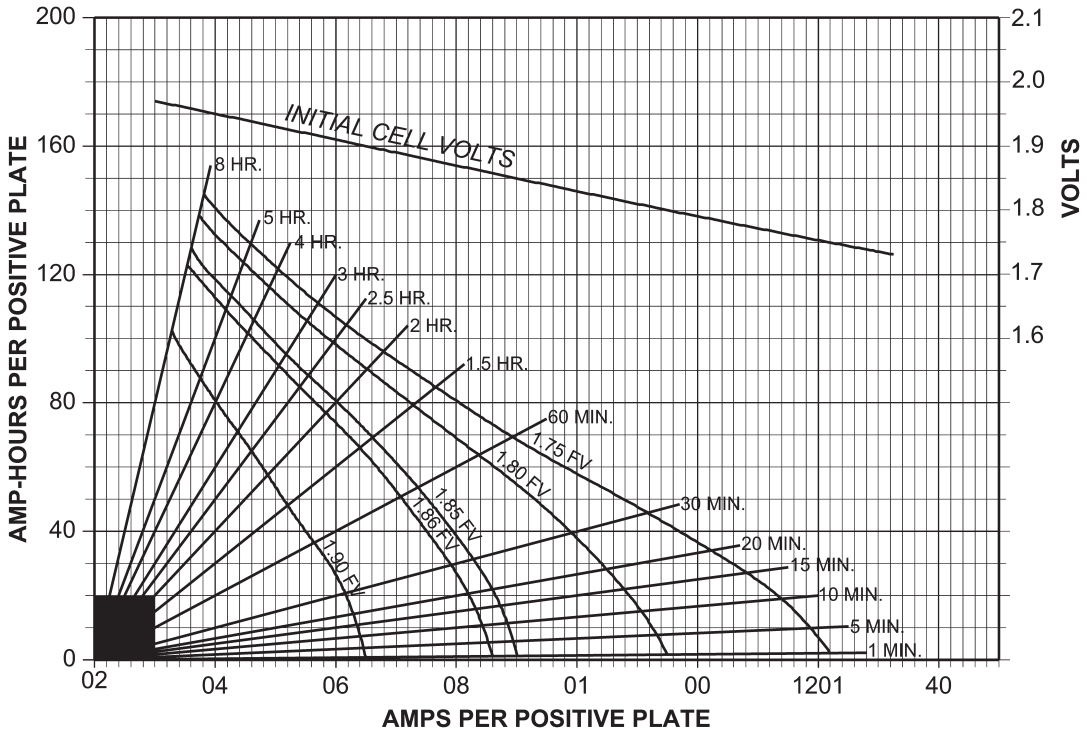

Figure E.7—Completed discharge characteristic curve

E.3.1 Example 1

Suppose a prospective buyer has a requirement for a battery capable of carrying a load of 400 A for 1 h without the battery voltage falling below 1.75 average volts per cell.

From the sample discharge characteristic curve (Figure E.8), you see the 1.75 V line intersects the 1 h time line at 69.3 A per positive plate. If you divide 1 h capability (69.3 A per positive plate) into the required load (400 A), the answer is the number of positive plates required by the ABC series battery to which the curve applies.

In this example, 5.77 positive plates are required, but the next highest whole number of positive plates is needed-in this case, six. A battery consisting of 13 plates (6 positive and 7 negative) is required.

E.3.2 Example 2

Suppose a user already has a 15 plate cell (7 positive plates) and wants to know how long it will carry 700 A before reaching 1.75 V per cell.

Divide 700 A by the number of positive plates (7) which equals 100 A per positive plate.

Next, find where 100 A per positive plate intersects the 1.75 voltage line, and then note the corresponding value of ampere-hours on the vertical axis—36 Ah per positive plate (Figure E.9).

Finally, divide 100 A per positive plate into 36 Ah per positive plate (amperes into ampere-hours equals hours) to get 0.36 h, which is 21.6 min (0.36 h × 60 min/h). This is the reserve time with a 700 A load.

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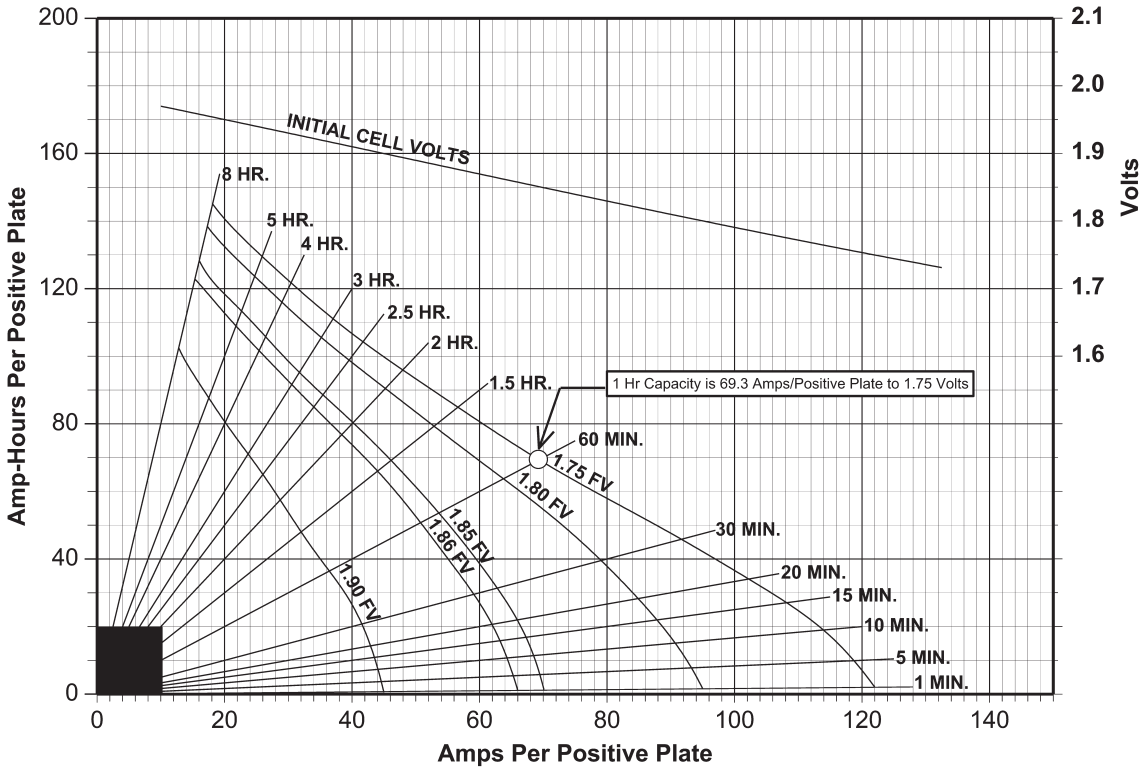

Figure E.8—One hour sizing calculation

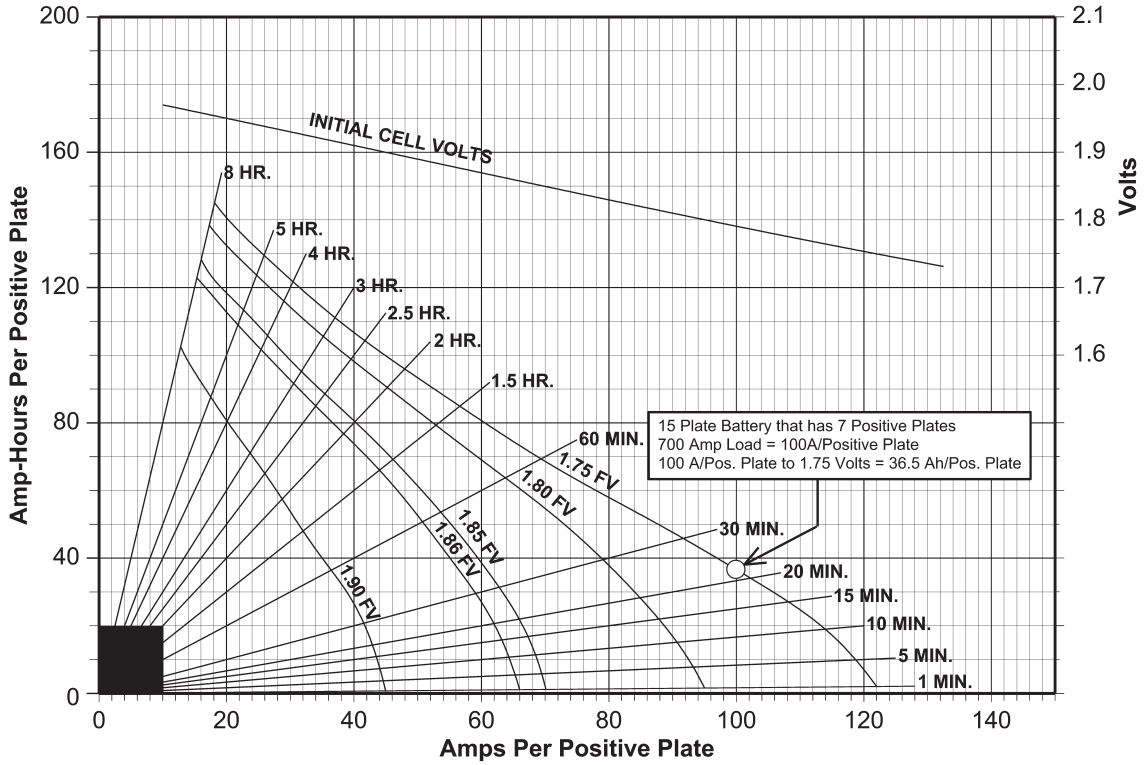

Figure E.9—100 A/positive plate load calculation

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E.3.3 Example 3

Nontypical reserve times and end voltages can be calculated. Suppose the cell size required for a 2.5 h reserve, 350 A load, and 1.83 minimum average cell voltage needs to be determined.

First, draw in a 2.5 h time line on the characteristic curve. Do this by choosing an ampere value on the horizontal axis (for example, 40 A per positive plate). Multiply this by 2.5 h (40 A/positive plate × 2.5 h = 100 Ah/positive plate). Draw a line from the origin through the point where 40 A/positive plate and 100 Ah per positive plate intersect. This is the 2.5 h line (Figure E.10).

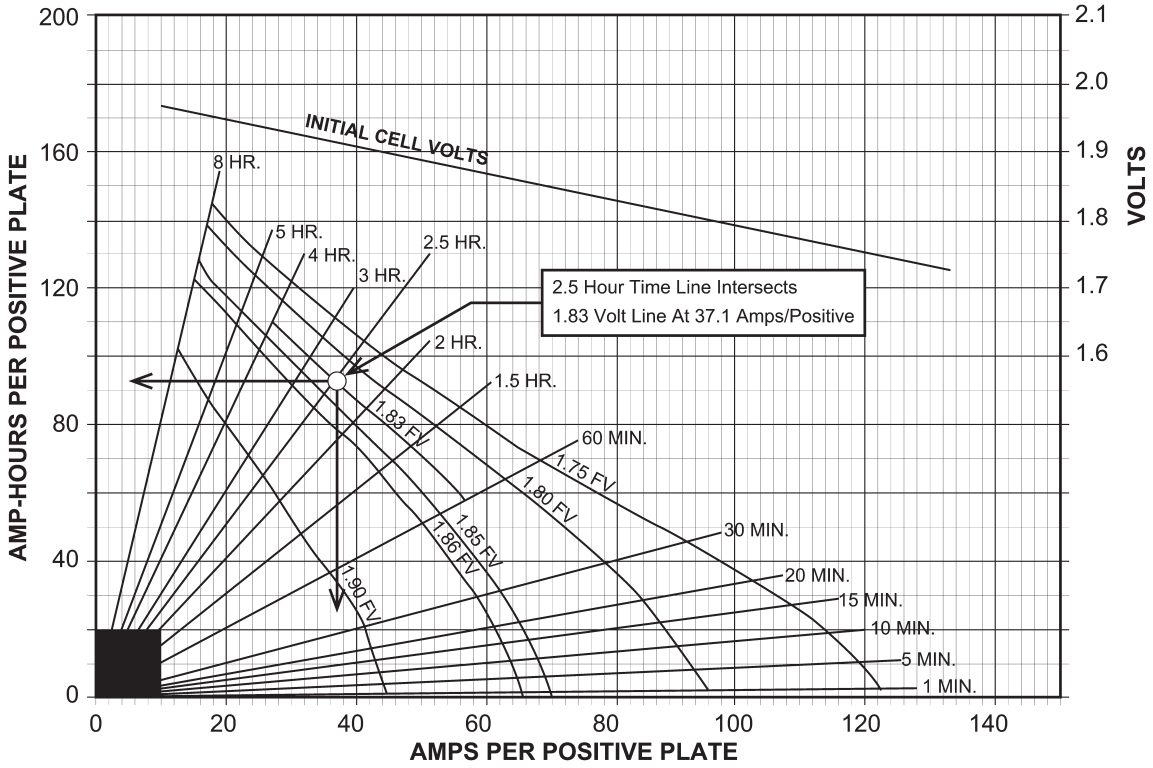

Figure E.10—Sizing calculation 3

Next, determine where a 1.83 final volts line would intersect the 2.5 h time line (interpolate between the 1.80 and 1.85 voltage lines shown) and find the corresponding amperes per positive plate value on the horizontal axis (37.1 A per positive plate, as shown in Figure E.10).

NOTE—Voltages can be interpolated; time lines cannot and are drawn based on test data.

Now, determine the number of positive plates required. In this instance, 350 A divided by 37.1 A per positive plate = 9.43 or 10 positive plates. The cell meeting this requirement is the ABC-21.

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Annex F

(informative)

Random loads

Subclause 4.2.7 of this recommended practice addresses random loads and their application in the battery sizing process. The method described is for loads that actuate randomly anytime during a duty cycle or for which the actual actuation time in the duty cycle is unknown. However, if more specific information regarding the timing of a random load can be ascertained, it may result in a requirement for a smaller battery, which is typically desirable for economic reasons. This is typically achieved by ascertaining enough information to allow the random load to be reclassified as either a momentary load or a non-continuous load and placed into the load profile appropriately.

Sometimes enough information can be determined to classify the load as random within a portion of the duty cycle. For example if it is known that a specific load could only operate during the last hour of a duty cycle, then the load could be added to only the most critical portion of the last hour. If this were the case for the random load shown in the battery sizing example of Annex A, the result would be a required battery size of XYZ-25 (11.15 plates required) instead of the XYZ-27 (12.64 positive plates required) as shown in Figure F.1 and Figure F.2.

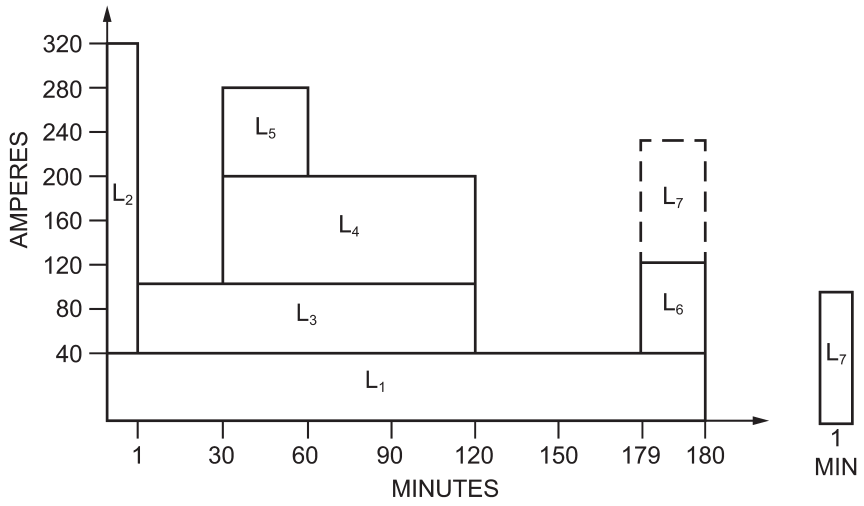

Figure F.1—Random load in last hour

If the specific actuation time of a typical random load is not determinable (often because it is process based), general operation information may provide enough information to allow the load to be considered in a period of the duty cycle that is not the most severe. Often, it is easier to determine when a load will not actuate than to determine when it may. Additional review and or analysis of the load and its operation within the system it is operating is required but may yield significant benefit. The larger the magnitude of the random load, the greater the potential benefit of selecting the most economical cell size.

As an example: For the random load described in the sizing example of Annex A, assume that it can be determined that the load does not randomly actuate within the second hour of the duty cycle (between 60 min and 120 min). In this example, the random load could be classified as a momentary load at the end of the 1st minute, the end of the first hour, or at the end of the scenario (ending in the 180th min) and would yield the same result. This change, as shown in Figure°F.1 through Figure°F.6, would result in a reduction in the required cell size to an XYZ-25 (11.13 to 11.15 positive plates required) instead of the XYZ-27 (12.6 positive plates required) as shown in Annex A.

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Project: Example using R_T Capacity Factor — Date: 9/17/1977 — Page: 1

Lowest Expected Electrolyte Temp: 65 °F — Minimum Cell Voltage: 1.75 — Cell Mfg: ABC Co — Cell Type: XYZ — Sized By: J.W.A

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity at T Min Rate (6A) Amps / Pos (R_T) or (6B) K Factor (K_T)	Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs — Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.							
1	A1= 320	A1–0= 320	M1= 1	T=M1= 1	104	3.08	***
					Sec 1 Total	3.08	***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.							
1	A1=	A1–0=	M1=	T=M1+M2=			
2	A2=	A2–A1=	M2=	T=M2=			
					Sec 2 Sub Tot / Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.							
1	A1= 320	A1–0= 320	M1= 1	T=M1+M2+M3= 60	40.0	8.00	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3= 59	40.0		–5.50
3	A3= 280	A3–A2= 180	M3= 30	T=M3= 30	55.4	3.25	
					Sec 3 Sub Tot	11.25	–5.50
					Total	5.75	***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.							
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M4= 120	27.5	11.64	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3+M4= 119	27.5		–8.00
3	A3= 280	A3–A2= 180	M3= 30	T=M3+M4= 90	32.5	5.54	
4	A4= 200	A4–A3= –80	M4= 60	T=M4= 60	40.0		–2.00
					Sec 4 Sub Tot	17.18	–10.00
					Total	7.18	***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.							
1	A1=	A1–0=	M1=	T=M1+. . . M5=			
2	A2=	A2–A1=	M2=	T=M1+. . . M5=			
3	A3=	A3–A2=	M3=	T=M3+M4+M5=			
4	A4=	A4–A3=	M4=	T=M4+M5=			
5	A5=	A5–A4=	M5=	T=M5=			
					Sec 5 Sub Tot / Total		***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.							
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M6= 180	21.5	14.88	
2	A2= 100	A2–A1= –220	M2= 29	T=M1+. . . M6= 179	21.5		–10.23
3	A3= 280	A3–A2= 180	M3= 30	T=M1+. . . M6= 150	24.0	7.50	
4	A4= 200	A4–A3= –80	M4= 60	T=M4+M5+M6= 120	27.5		–2.91
5	A5= 40	A5–A4= –160	M5= 59	T=M5+M6= 60	40.0		–4.00
6	A6= 220	A6–A5= 180	M6= 1	T=M6= 1	104.0	1.73	
					Sec 6 Sub Tot	24.11	–17.14
					Total	6.97	***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.							
1	A1=	A1–0=	M1=	T=M1+. . . M7=			
2	A2=	A2–A1=	M2=	T=M1+. . . M7=			
3	A3=	A3–A2=	M3=	T=M1+. . . M7=			
4	A4=	A4–A3=	M4=	T=M1+. . . M7=			
5	A5=	A5–A4=	M5=	T=M5+M6+M7=			
6	A6=	A6–A5=	M6=	T=M6+M7=			
7	A7=	A7–A6=	M7=	T=M7=			
					Sec 7 Sub Tot / Total		***
Random Equipment Load Only (if needed)							
R	AR=	AR–0 =	MR=	T=MR=			***

Maximum Section Size (8) 7.18 + Random Section Size (9) 0.0 = Uncorrected Size – (US) (10) 7.18.

US (11) 7.18 × Temp Corr (12) 1.08 × Design Marg (13) 1.15 × Aging Factor (14) 1.25 = (15) 11.15.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) 12

(B) - Ampere Hours. Therefore cell (17) XYZ-25 is required.

Figure F.2—Battery sizing for random load in last hour

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If multiple random loads are being considered, additional care is required to understand what, if any, interactions exist between these loads. Multiple random loads can be combined within specific periods and their cumulative impact reduced by having them spread through the profile. When investigating the actual operation of loads classified as random loads, it may become clear that some of the loads cannot operate simultaneously. These reasons include self-excluding conditions, relay propagation, or even related process conditions (such as a two valves operating to open but Valve 1 operating on receipt of a "Tank 1 level high" signal and Valve 2 operating on a "Tank 1 low level"). In these cases, it is determined that the modeling include only one of the valves as a random load.

If operating times can be determined to be limited in some way (for example, Valve 1 can only occur within the 30 min and Valve 2 could only occur in the last hour) the loads could be inserted into the profile as momentary loads at the limiting part of the profile during the specified period. If it is unclear which portion of the period is limiting, then the sizing should be run without the random load to determine the limiting step. Once this is determined, the sizing should be re-run with the random load added to the limiting step.

In the example shown in Annex A, it may be unclear if it would be more limiting to show Valve 1 as a load during the first minute or at the end of the 30 min. Two cases of the sizing sheet should be performed to determine at which time the load would be most limiting.

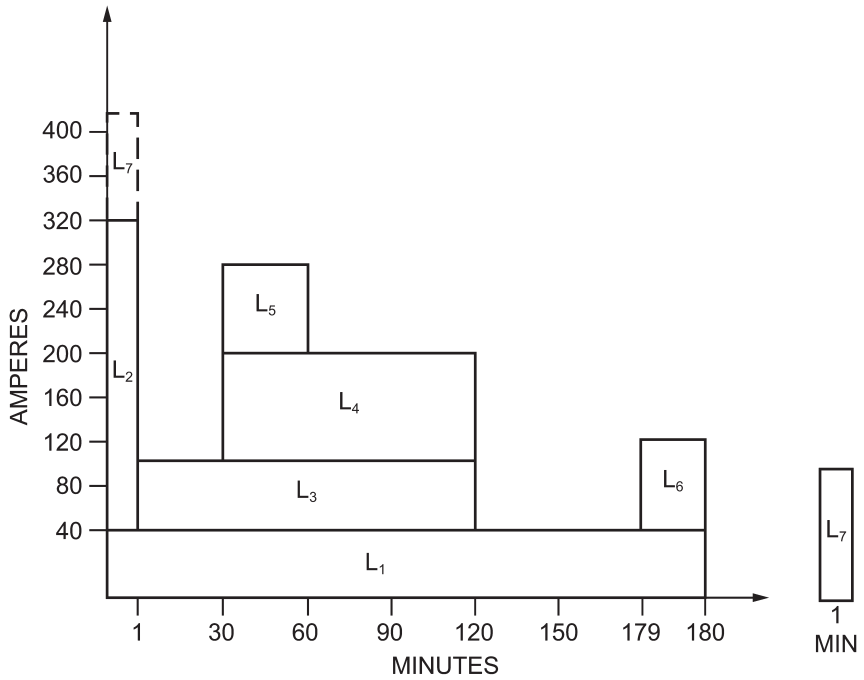

Figure F.3—Random load in first minute

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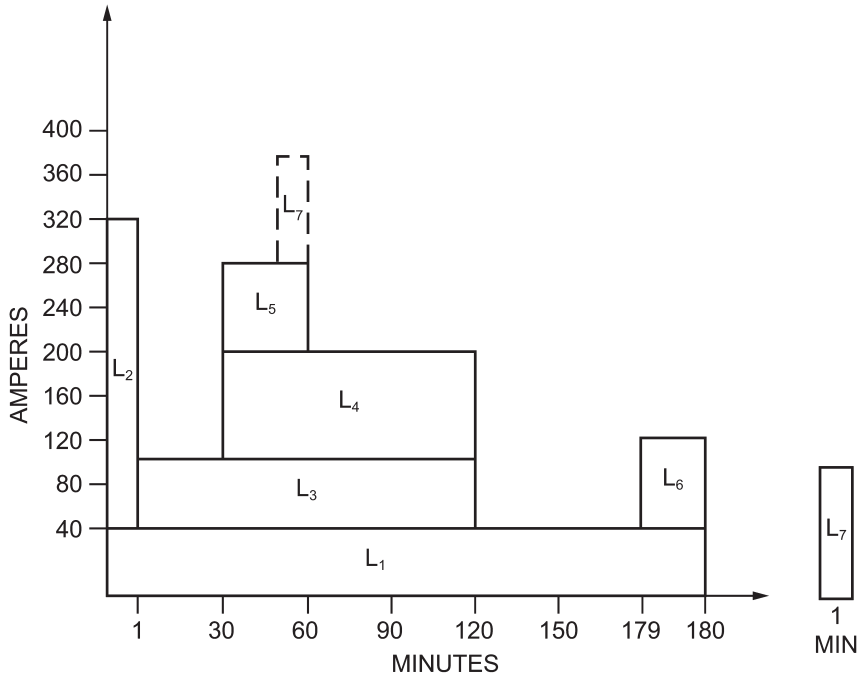

Figure F.4—Random load at end of first hour

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Project: Example using R_T Capacity Factor — Date: 9/17/1977 — Page: 1

Lowest Expected Electrolyte Temp: 65 °F — Minimum Cell Voltage: 1.75 — Cell Mfg: ABC Co — Cell Type: XYZ — Sized By: J.W.A

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity at T Min Rate (6A) Amps / Pos (R_T) or (6B) K Factor (K_T)	Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs — Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.							
1	A1= 420	A1–0= 420	M1= 1	T=M1= 1	104	4.04	***
					Sec 1 Total	4.04	***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.							
1	A1=	A1–0=	M1=	T=M1+M2=			
2	A2=	A2–A1=	M2=	T=M2=			
					Sec 2 Sub Tot / Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.							
1	A1= 420	A1–0= 420	M1= 1	T=M1+M2+M3= 60	40.0	10.50	
2	A2= 100	A2–A1= –320	M2= 29	T=M2+M3= 59	40.0		–8.00
3	A3= 280	A3–A2= 180	M3= 30	T=M3= 30	55.4	3.25	
					Sec 3 Sub Tot	13.75	–8.00
					Total	5.75	***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.							
1	A1= 420	A1–0= 420	M1= 1	T=M1+. . . M4= 120	27.5	15.27	
2	A2= 100	A2–A1= –320	M2= 29	T=M2+M3+M4= 119	27.5		–11.64
3	A3= 280	A3–A2= 180	M3= 30	T=M3+M4= 90	32.5	5.54	
4	A4= 200	A4–A3= –80	M4= 60	T=M4= 60	40.0		–2.00
					Sec 4 Sub Tot	20.81	–13.64
					Total	7.17	***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.							
1	A1=	A1–0=	M1=	T=M1+. . . M5=			
2	A2=	A2–A1=	M2=	T=M1+. . . M5=			
3	A3=	A3–A2=	M3=	T=M3+M4+M5=			
4	A4=	A4–A3=	M4=	T=M4+M5=			
5	A5=	A5–A4=	M5=	T=M5=			
					Sec 5 Sub Tot / Total		***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.							
1	A1= 420	A1–0= 420	M1= 1	T=M1+. . . M6= 180	21.5	19.53	
2	A2= 100	A2–A1= –320	M2= 29	T=M1+. . . M6= 179	21.5		–14.88
3	A3= 280	A3–A2= 180	M3= 30	T=M1+. . . M6= 150	24.0	7.50	
4	A4= 200	A4–A3= –80	M4= 60	T=M4+M5+M6= 120	27.5		–2.91
5	A5= 40	A5–A4= –160	M5= 59	T=M5+M6= 60	40.0		–4.00
6	A6= 120	A6–A5= 80	M6= 1	T=M6= 1	104.0	0.77	
					Sec 6 Sub Tot	27.80	–21.79
					Total	6.01	***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.							
1	A1=	A1–0=	M1=	T=M1+. . . M7=			
2	A2=	A2–A1=	M2=	T=M1+. . . M7=			
3	A3=	A3–A2=	M3=	T=M1+. . . M7=			
4	A4=	A4–A3=	M4=	T=M1+. . . M7=			
5	A5=	A5–A4=	M5=	T=M5+M6+M7=			
6	A6=	A6–A5=	M6=	T=M6+M7=			
7	A7=	A7–A6=	M7=	T=M7=			
					Sec 7 Sub Tot / Total		***
Random Equipment Load Only (if needed)							
R	AR=	AR–0 =	MR=	T=MR=			***

Maximum Section Size (8) 7.17 + Random Section Size (9) 0 = Uncorrected Size – (US) (10) 7.17.

US (11) 7.17 × Temp Corr (12) 1.08 × Design Marg (13) 1.15 × Aging Factor (14) 1.25 = (15) 11.13.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) 12

(B) - Ampere Hours. Therefore cell (17) XYZ-25 is required.

Figure F.5—Battery sizing for random load in first minute

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Project: Example using R_T Capacity Factor Date: 9/17/1977 Page: 1

Lowest Expected Electrolyte Temp: 65 °F		Minimum Cell Voltage: 1.75		Cell Mfg: ABC Co	Cell Type: XYZ		Sized By: J.W.A	
(1)	(2)	(3)	(4)	(5)	(6)		(7)	
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity at T Min Rate (6A) Amps / Pos (R_T) or (6B) K Factor (K_T)		Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.								
1	A1= 320	A1–0= 320	M1= 1	T=M1= 1	104		3.08	***
					Sec 1	Total	3.08	***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.								
1	A1=	A1–0=	M1=	T=M1+M2=				
2	A2=	A2–A1=	M2=	T=M2=				
					Sec 2	Sub Tot / Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.								
1	A1=	A1–0=	M1=	T=M1+M2+M3=				
2	A2=	A2–A1=	M2=	T=M2+M3=				
3	A3=	A3–A2=	M3=	T=M3=				
					Sec 3	Sub Tot / Total		***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.								
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M4= 60	40.0		8.00	
2	A2= 100	A2–A1= –220	M2= 29	T=M2+M3+M4= 59	40.0			–5.50
3	A3= 280	A3–A2= 180	M3= 29	T=M3+M4= 30	55.4		3.25	
4	A4= 380	A4–A3= 100	M4= 1	T=M4= 1	104.0		0.96	–2.00
					Sec	Sub Tot	12.21	–5.50
					4	Total	6.71	***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.								
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M5= 120	27.5		11.64	
2	A2= 100	A2–A1= –220	M2= 29	T=M1+. . . M5= 119	27.5			–8.00
3	A3= 280	A3–A2= 180	M3= 29	T=M3+M4+M5= 90	32.5		5.54	
4	A4= 380	A4–A3= 100	M4= 1	T=M4+M5= 61	40		2.50	
5	A5= 200	A5–A4= –180	M5= 60	T=M5= 60	40			–4.50
					Sec	Sub Tot	19.68	–12.50
					5	Total	7.18	***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.								
1	A1=	A1–0=	M1=	T=M1+. . . M6=				
2	A2=	A2–A1=	M2=	T=M1+. . . M6=				
3	A3=	A3–A2=	M3=	T=M1+. . . M6=				
4	A4=	A4–A3=	M4=	T=M4+M5+M6=				
5	A5=	A5–A4=	M5=	T=M5+M6=				
6	A6=	A6–A5=	M6=	T=M6=				
					Sec	Sub Tot		
					6	Total		***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.								
1	A1= 320	A1–0= 320	M1= 1	T=M1+. . . M7= 180	21.5		14.88	
2	A2= 100	A2–A1= –220	M2= 29	T=M1+. . . M7= 179	21.5			–10.23
3	A3= 280	A3–A2= 180	M3= 29	T=M1+. . . M7= 150	24		7.50	
4	A4= 380	A4–A3= 100	M4= 1	T=M1+. . . M7= 121	27.5		3.54	
5	A5= 200	A5–A4= –180	M5= 60	T=M5+M6+M7= 120	27.5			–6.55
6	A6= 40	A6–A5= –160	M6= 59	T=M6+M7= 60	40			–4.00
7	A7= 120	A7–A6= 80	M7= 1	T=M7= 1	104		0.77	
					Sec	Sub Tot	26.79	–20.78
					7	Total	6.01	***
Random Equipment Load Only (if needed)								
R	AR=	AR–0 =	MR=	T=MR=				***

Maximum Section Size (8) 7.18 + Random Section Size (9) 0.0 = Uncorrected Size – (US) (10) 7.18.

US (11) 7.18 × Temp Corr (12) 1.08 × Design Marg (13) 1.15 × Aging Factor (14) 1.25 = (15) 11.15.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) 12

(B) - Ampere Hours. Therefore cell (17) XYZ-25 is required.

Figure F.6—Battery sizing for random load at end of first hour

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Annex G

(informative)

Full-size worksheet

On the next page is a full-sized worksheet.[8]

[8]Users of this recommended practice may freely reproduce the form in this annex so that it can be used for their intended purpose.

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Project: Date: Page:

Lowest Expected Electrolyte Temp: °F | Minimum Cell Voltage: | Cell Mfg: | Cell Type: | Sized By:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
	Load	Change in Load	Duration of Period	Time to End of Section	Capacity at T Min Rate (6A) Amps / Pos (R_T) or	Required Section Size (3) ÷ (6A) = Positive Plates or (3) × (6B) = Rated Amp Hrs	
Period	(amperes)	(amperes)	(minutes)	(minutes)	(6B) K Factor (K_T)	Pos Values	Neg Values
Section 1 - First Period Only - If A2 is greater than A1, go to section 2.							
1	A1=	A1–0=	M1=	T=M1=			***
					Sec 1 Total		***
Section 2 - First Two Periods Only - If A3 is greater than A2, go to section 3.							
1	A1=	A1–0=	M1=	T=M1+M2=			
2	A2=	A2–A1=	M2=	T=M2=			
					Sec 2 Sub Tot		
					Total		***
Section 3 - First Three Periods Only - If A4 is greater than A3, go to section 4.							
1	A1=	A1–0=	M1=	T=M1+M2+M3=			
2	A2=	A2–A1=	M2=	T=M2+M3=			
3	A3=	A3–A2=	M3=	T=M3=			
					Sec 3 Sub Tot		
					Total		***
Section 4 - First Four Periods Only - If A5 is greater than A4, go to section 5.							
1	A1=	A1–0=	M1=	T=M1+. . . M4=			
2	A2=	A2–A1=	M2=	T=M2+M3+M4=			
3	A3=	A3–A2=	M3=	T=M3+M4=			
4	A4=	A4–A3=	M4=	T=M4=			
					Sec 4 Sub Tot		
					Total		***
Section 5 - First Five Periods Only - If A6 is greater than A5, go to section 6.							
1	A1=	A1–0=	M1=	T=M1+. . . M5=			
2	A2=	A2–A1=	M2=	T=M1+. . . M5=			
3	A3=	A3–A2=	M3=	T=M3+M4+M5=			
4	A4=	A4–A3=	M4=	T=M4+M5=			
5	A5=	A5–A4=	M5=	T=M5=			
					Sec 5 Sub Tot		
					Total		***
Section 6 - First Six Periods Only - If A7 is greater than A6, go to section 7.							
1	A1=	A1–0=	M1=	T=M1+. . . M6=			
2	A2=	A2–A1=	M2=	T=M1+. . . M6=			
3	A3=	A3–A2=	M3=	T=M1+. . . M6=			
4	A4=	A4–A3=	M4=	T=M4+M5+M6=			
5	A5=	A5–A4=	M5=	T=M5+M6=			
6	A6=	A6–A5=	M6=	T=M6=			
					Sec 6 Sub Tot		
					Total		***
Section 7 - First Seven Periods Only - If A8 is greater than A7, go to section 8.							
1	A1=	A1–0=	M1=	T=M1+. . . M7=			
2	A2=	A2–A1=	M2=	T=M1+. . . M7=			
3	A3=	A3–A2=	M3=	T=M1+. . . M7=			
4	A4=	A4–A3=	M4=	T=M1+. . . M7=			
5	A5=	A5–A4=	M5=	T=M5+M6+M7=			
6	A6=	A6–A5=	M6=	T=M6+M7=			
7	A7=	A7–A6=	M7=	T=M7=			
					Sec 7 Sub Tot		
					Total		***
Random Equipment Load Only (if needed)							
R	AR=	AR–0=	MR=	T=MR=			***

Maximum Section Size (8) _____ + Random Section Size (9) _____ = Uncorrected Size – (US) (10) _____.

US (11) _____ × Temp Corr (12) _____ × Design Marg (13) 1. _____ × Aging Factor (14) 1. _____ = (15) _____.

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

(A) - Positive Plates.

Required cell size (16) _____

(B) - Ampere Hours. Therefore cell (17) _____ is required.

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Annex H

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Hoxie, E. A., "Some discharge characteristics of lead-acid batteries," AIEE Transactions Part II: Applications and Industry, vol. 73, no. 1, pp. 17–22, March 1954.

[B2] IEEE Std 323™-2003, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

[B3] IEEE Std 535™-2006, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations.

[B4] IEEE Std 627™-1980 (Reaff 1997), IEEE Standard for Design Qualification of Safety Systems Equipment Used in Nuclear Power Generating Stations (withdrawn).[9]

[B5] IEEE Std 946™-2004, IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations.

[B6] IEEE Std 1578™-2007, IEEE Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management.

[B7] IEEE Std 1660™, Application and Management of Stationary Batteries Used in Cycling Service.

[9]IEEE Std 627-1980 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).

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